DIVER OPERATED TOOLS AND APPLICATIONS FOR UNDERWATER CONSTRUCTION

BY

ROBERT R. SALTSMAN

A REPORT PRESENTED TO THE GRADUATE COMMITTEE OF THE DEPARTMENT OF CIVIL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA

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SUMMER 1987

DEDICATED

TO

My wife, Jill

and

my daughter, Katie Marie

and

The United States Navy

TABLE OF CONTENTS

TABLE OF CONTENTS (CON'T)

TABLE OF CONTENTS (CON'T)

PREFACE

The rationale for choosing underwater construction as my master's report topic is due to the fact that our undersea environment will be the "new world" for mankind. Already underwater activity is becoming increasingly more important each year. Tapping the ocean's vital resources for food, energy, and mineral wealth will require advanced knowledge in underwater construction technology to support these operations. The skills of mechanical, electrical, structural, civil, and other engineering disciplines will be required to successfully construct new supporting ocean facilities.

The problems with underwater construction are international as well as multi-disciplinary, and the triangle of technical, economic, and political aspects is always present.

In 1948 the United States Navy began operating the Navy Civil Engineering Laboratory in Port Hueneme, California. Since then they have conducted a full time effort to the research and development of underwater construction and repair. They have also acted as a technological hub for support of the U.S. Navy marine and shore facilities. In addition the U.S. Navy has two underwater construction teams (UCT'S); on the East and West Coasts of the United States.

Because I am a United States Naval Officer interested in oceanography and construction, underwater construction is important to me. I truly believe, it is also a documented fact, that underwater operations and construction on the seabed will represent a significant economic and strategic importance to the United States. With this knowledge I can better serve the Navy and my country and perhaps become actively involved with the Navy's underwater programs.

In addition man must strike a balance with his environment. The key to his survival will rely upon his capability to live and work in the ocean. Therefore construction of underwater facilities will become more important each year.

ABSTRACT

This paper investigates diver operated tools and techniques for underwater construction. Diving history, underwater physics, diver physiology, and various diving apparatus are briefly discussed. Underwater tools, buoyancy lift bags, welding equipment and techniques, and diver excavation are examined in this report. Operations planning, scheduling, and costs are briefly reviewed as it pertains to underwater construction. This report emphasizes the importance of underwater construction to the development of the continental shelf which has significant social, political, and strategic implications. Future underwater facilities, tools, and even the diver of tomorrow (the aquanaut) are correlated to the future development and exploitation of the world's underwater resources.

CHAPTER ONE

INTRODUCTION

The overwhelming significance of the earth's underwater environment is self evident from the fact that the oceans cover over 70% of the earth's surface, a total marine area of more than 139,480,000 square miles. Bathymetric charts of the world's oceans indicate that most of the continents are surrounded entirely by a continental shelf. "Of the total marine area of the world, 7 1/2 % comes within the continental shelf at a depth generally not exceeding 200 meters (600 feet). The width of the shelf varies from almost zero, as along parts of the west coast of Africa, to a maximum of 1500 km from the coasts of Louisiana and Texas" (1:4). Because current diving operations are capable below 300 meters, the ability to operate and build structures on the continental shelf exists today. Most existing structures are a result of mining, petroleum, and research operations which concentrate on tapping underwater resources.

As land resources dwindle, underwater resources will be necessary as a source of required material, i.e.; food, minerals, and possibly areas for expansion. As diving operations technology advances, more of the ocean will be within the realm of man's control.

However, because the world's oceans are so important to the ecology of earth, man must consider his venture into the sea with wisdom and forethought. He must not repeat his terrestrial mistakes of disregard for the environment. Already man has learned that his actions can have detrimental effects on the complex ecosystems of the earth. The recent concern regarding the deterioration of the ozone layer and the destruction of subtropical forests affecting the earth's weather patterns is but two examples of why our leaders must move in a direction of greater international cooperation and management of world resources.

The purpose of this paper is to provide a basic introduction to diver operated tools, capabilities, limitations, and identify some current underwater construction applications and techniques utilizing divers. This paper will also examine the general feasibility of diver supported underwater construction.

CHAPTER TWO

APPLICATIONS OF UNDERWATER CONSTRUCTION

The current need for underwater construction is mostly derived from the oil and mining industry. In general, undersea commercial activities primarily involve the following (2:8):

1. the exploitation of sea floor resources
2. the harvesting of resources from sea water
3. communications and transportation via undersea cables and pipelines
4. sea-based power systems
5. sports and recreation

Scientific exploration is also very important. "The oceans control the weather, contain a multitude of resources, provide a ready means of transportation, and include areas of basic information on the formation of the earth and the growth of the continents" (2:10).

Construction of undersea platforms will be necessary to sustain numerous scientific research projects. These platforms can support various sensors to measure temperature, salinity, currents and other phenomenon. Table 1, developed by the National Research Council's Marine Board Panel on ocean survey needs, indicates the types and locations of measurements required to assist many scientific investigations.

Table 1

Needs Parameters Related to Regime and Time Interval of Measurement[a]

Parameter	Air-sea interface (+10 to −10 m)	Upper water column (−10 to −500 m)	Lower water column (> 500 m)	Bottom	Subbottom
Temperature	2, 3	2, 3	2, 6		
Surface meteorology	1, 3				
Sea-swell-surf	2, 3				
Surge	2, 3				
Currents	1, 2, 3	1, 2, 3	1, 2, 3		
Tides	1				
Ice	2, 3, 5				
Salinity	2, 3	2, 3	2, 6		
Pollutants	1, 2, 6	1, 2, 6	1, 2, 6	2, 6	
Noise	2, 6	2, 6	2, 6		
Hydrodynamic forces	2, 6	2, 6	2, 6		
Biomass	2, 3, 5, 6	2, 3, 5, 6	2, 3, 5, 6	2, 3, 5, 6	
Nutrients	2, 3, 5, 6	2, 3, 5, 6	2, 3, 5, 6	2, 3, 5, 6	
Oxygen	2, 3, 5, 6	2, 3, 5, 6	2, 3, 5, 6	2, 3, 5, 6	
Gravity					4, 6
Electrical		4, 6	4, 6	4, 6	
Magnetics					4, 6
Radiometric				2, 4, 6	2, 4, 6
Seismic					4, 6
Geothermal				2, 4, 6	2, 4, 6
Geology				4, 6	4, 6
Eng. properties				4, 6	4, 6
Phys. properties				4, 6	4, 6
Geomorphology				2, 4, 6	
Bathymetry				4, 6	
Turbidity	2, 3, 5, 6	2, 3, 5, 6	2, 3, 5, 6		
Rheology				4, 6	
Geochemistry				4, 6	4, 6

[a]The numbers in the table refer to the following remarks: 1. Continuous, 2. Periodic, 3. Synoptic, 4. One-shot, 5. Seasonal, and 6. Detail verification.
Source: "Summary of the Proceedings of the Workshop at Airlie, Virginia, or Perspectives for Ocean Exploration and Survey Systems 1975-1985," a working document prepared for the use of the participants (1972). Courtesy of the National Research Council.

Source: (2:12)

Figure 1 shows the U.S. Navy, Civil Engineering Laboratory's Sea Floor Construction Experiment, SEACON II, in which an instrumented tri-moor cable structure was constructed in 1974 in the Santa Monica Basin (2,900 feet deep). Navy Facilities Engineering Command (NAVFAC) sponsored the project with the primary objective of measuring the three dimensional cable structure's steady state response to ocean currents and then using the acquired measurements to validate analytical design models. "A secondary goal was to provide a demonstration and critical evaluation of recent developments in ocean engineering technology required to site, design, implant, and operate large fixed subsea cable structures" (3:1).

Construction of the tri-moor platform involved the coordinated use of prefabricated cable construction, diver and submersible support, and surface support all of which will be further discussed in subsequent chapters.

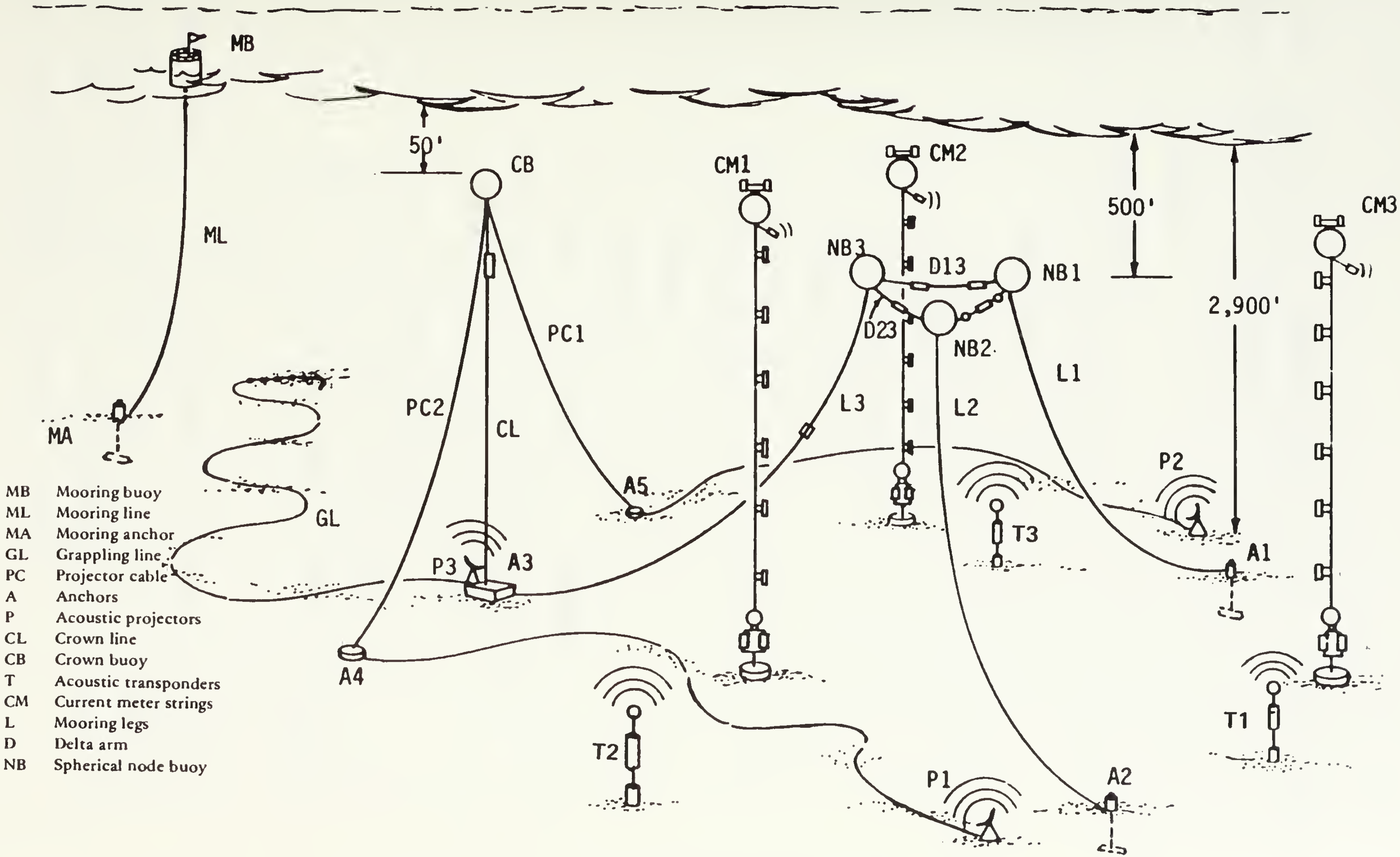


Figure 1 - Instrumented Tri-moor
Source: (3:22)

Other significant applications of diver and/or ROV supported underwater construction include:

1. cables
2. pipelines
3. coastal installations
    A. outfalls
        1. sewage plants
        2. power plants
    B. airport extensions
    C. bridges and piers
4. navigational aids
5. waste facilities
    A. nuclear
    B. chemical
6. astronomy telescopes, DUMAND (deep underwater muon and neutrino detector)
7. offshore oil and gas facilities
8. offshore mining facilities
9. undersea military installations
10. OTEC Plants (ocean thermal energy conversion)

From the above it is evident that there are a myriad of applications requiring the use of subsurface construction. The list is by no means exhaustive and new methods and requirements continue to evolve.

CHAPTER THREE

DIVING OPERATIONS AND CHARACTERISTICS

3.1 GENERAL

This chapter will discuss the history of diving operations, examine basic underwater physics, diver physiology, and identify the types of current diving apparatus used. The capabilities and limitations of divers, and their methods of communication are also discussed. These concepts are essential to understanding the nature of underwater construction because they represent restrictions and capabilities of underwater labor.

3.2 HISTORY

Man's quest to build submarine structures and work under the sea is deeply rooted in the need to conduct military and salvage operations, to engage in underwater commerce, and to expand the frontiers of knowledge through exploration and research.

The diving profession can be traced back more than 5000 years. Early diving efforts were confined to relatively shallow waters (less than 100 feet), where divers harvested a variety of commercial materials including food, sponges, coral, and mother of pearl (4:1).

Early records of diving can be found in the writings of the Greek historian Herodotus. He wrote about the story of a diver named Scyllis, who was employed by the Persian King Xerxes to recover sunken treasure in the 5th century B.C. (4:1).

Early divers were active in military operations such as cutting anchor lines to set enemy ships adrift, boring or punching holes in the bottom of ships, building harbor defenses, and destroying enemy installations abroad. During the 5th century B.C. Syracusans erected submarine barriers of wood to repel attacking Athenian landing barges in Syracuse, Sicily. The Athenians on their second attack used underwater swimmers to dismantle the barriers.

In 322 B.C., Alexander the Great used diving soldiers during his siege of the island stronghold of Tyre (now Lebanon). The divers were used to destroy the Phoenician's submerged boom defenses, and Alexander reportedly watched the operation from a diving bell (5:33).

It was not until the general period 1500-1800 A.D. that successful devices were developed and put to use which enabled divers to remain underwater for lengths of time measured in hours rather than in minutes. This was primarily the diving bell but also included various designs of diving dress.

Diving bells are literally bell shaped with the bottom open to the sea. These strong tubs are weighted to sink vertically thus trapping enough air for the diver to breathe for several hours. The principle of the bell can be easily observed by pushing an inverted drinking glass into a pail of water. The air inside the glass is slightly compressed by the water with the air pressure equaling the water pressure.

Because diving bells are suspended by a cable from the surface, they have no significant underwater maneuverability beyond that provided by moving the surface support ship. The diver can remain inside the bell positioned directly over his work or can venture outside for short periods of time while holding his breath.

First reference to an actual practical diving bell was made in 1531. Thereafter for several hundred years rudimentary but effective diving bells were used regularly. An American, William Phipps in the 1680's modified the diving bell technique by supplying his divers with air from a series of weighted, inverted buckets when attempting to recover sunken treasure.

In 1690 English Astronomer Edmund Halley also developed a diving bell and used the same technique as Phipps except that he used weighted barrels of air from the surface. Halley and four other people remained at 60 feet in the Thames River for almost 1.5 hours. Nearly 26 years later, he made an improved version of his diving bell and spent more than four hours at a depth of 66 feet (4:1-2). Figure 2 shows the diving bell he designed.

In 1715 another Englishman, John Lethbridge, developed a completely enclosed one man diving dress. This equipment was essentially a reinforced, leather covered, barrel of air with a glass porthole for viewing and two arm holes with watertight sleeves permitting the occupant to accomplish useful work. Like a diving bell, this dress was also slung from a surface support ship and maneuvered by moving the ship.

Several other designs similar to Lethbridge's diving dress were also developed, however they all suffered from the same basic limitation as did the diving bell. The diver had little freedom because he could not be continually supplied with fresh air in a practical manner. It was not until the turn of the eighteenth century that a technological breakthrough occurred with the development of a pump capable of delivering air under pressure.

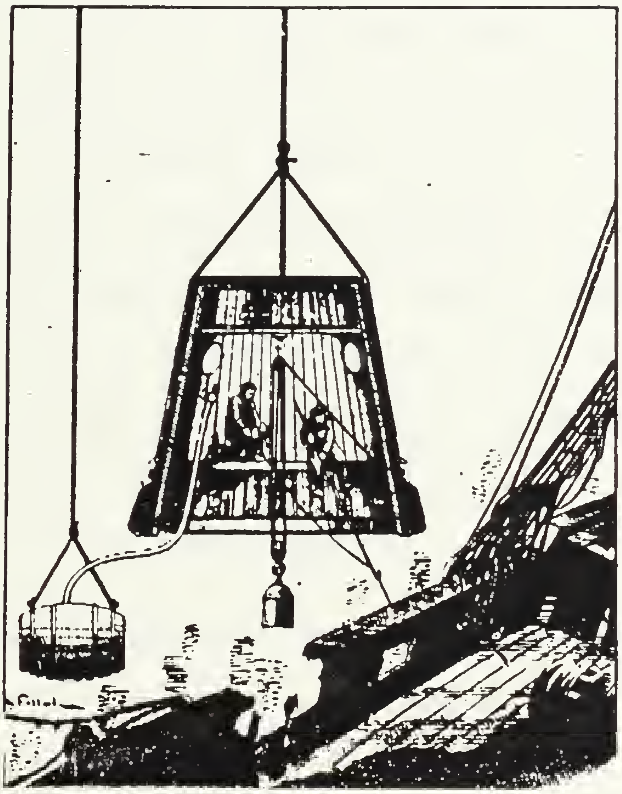


Figure 2 - Halley's Diving Bell
Source: (4:1-3)

Various diving dress were invented utilizing the new air pumps. However traditional credit for the development of the first practical diving dress was given to Augustus Siebe. He used a dress in which the diving helmet was sealed to a waist length suit that permitted the exhaust air to escape under the hem. By 1840, Siebe made a full length waterproof suit and added an exhaust valve to the system. This apparatus is the direct ancestor of the standard deep-sea diving dress in widespread use today.

In 1840 a unit of the British Royal Engineers was engaged in a difficult project of removing the remains of a sunken warship (HMS Royal George) which fouled a major fleet anchorage just outside of Portsmouth, England. The officer in charge, Colonel William Pasley, decided that his operation was an ideal opportunity to formally test and evaluate the various types of diving apparatuses. After his evaluation he recommended that the Siebe diving dress be adopted for future operations.

When Colonel Pasley's project was completed it was noted that all the divers suffered from attacks of rheumatism and hypothermia. The divers worked six to seven hours a day at depth of 60-70 feet. What appeared to be rheumatism was in fact a far more serious physiological problem later to be known as the "bends".

By the mid 1800's the diving bell was further improved and the newly developed high capacity air pump led to the construction of chambers large enough to permit several men to perform dry work on the sea floor. These chambers were known as caissons which is the French word for "big box". The caisson was particularly advantageous for projects involving excavation of bridge footings or tunnel sections requiring long periods of underwater work.

Caissons were designed to provide ready access to the surface through the use of an air lock. The air pressure inside the caisson was held constant while men, debris, and/or materials could be passed in and out.

The development of the caisson was a major step forward in engineering technology. Consequently their use expanded and the unexplained sickness that affected the caisson workers also became well known. In fact this caisson disease was originally coined the "bends" by workers on the Brooklyn Bridge in New York. The term may have originated out of the similarity between the contorted posture of the suffering worker and an awkward, forward-leaning stance affected by fashionable ladies of the time known as "the Grecian bend". The bends and other physiological problems involving underwater construction are discussed in section 3.4 of this chapter.

Because the bends was a problem with the underwater labor force, numerous inventors worked to create armored diving suits that would free the diver from any and all problems of pressure. However, the utility of most armored suits was questionable. They proved too clumsy and complicated to provide protection from extreme pressure and would not allow the diver to accomplish much work. In the 1930's the maximum design depth of such suits was 700 feet but that depth was never reached in actual diving. However, modern suits, now called one atmosphere diving dresses, have demonstrated their capability for specialized underwater tasks (4:1-7).

Because the diving bell, diving dress, and caisson all required surface support, maneuverability and flexibility was limited. Inventors sought a way to free the diver from surface support and the air hose. The obvious solution was to provide the diver with his own portable air supply. The solution was the self contained underwater breathing apparatus (SCUBA). Scuba took some time to evolve because neither a pump of sufficient capacity nor tanks of adequate strength existed to handle the high pressures needed for a practical air supply.

There are three types of scuba devices: open circuit, closed circuit, and semi closed circuit. Each type has its own history of development. The open circuit scuba takes air from the supply tank, is inhaled by the diver, and then exhausted directly to the surrounding water.

The basic closed system uses a tank of 100% oxygen to supply a breathing bag and the exhaust is recirculated through a chemical filter which removes carbon dioxide. Additional oxygen is then added from the tank to replace the lost oxygen.

The semi closed system combines the features of both systems. "Using a mixture of gases for breathing, the apparatus recycles the gas through a carbon dioxide removal canister and continually adds a small amount of oxygen-rich mixed gas to the system from a supply tank. The supply gas flow is pre-set to satisfy the body's oxygen demand and part of the recirculating mixed gas stream, equal to the supply gas flow, is continually exhausted to the water" (4:1-8). The semi-closed scuba provides significantly greater endurance than open-circuit systems in deep diving because the quantity of make up gas is constant regardless of depth.

The first important step in the development of scuba was the development of the demand regulator patented by Benoist Rouquayrol in 1866. This device adjusted the flow of air from the tank to meet the breathing and pressure requirements of the diver. Because the high pressure tanks did not exist at that time the regulator was utilized on surface supplied diving equipment and the technology turned to closed circuit designs. It was not until 60 years later that Rouquayrol's demand regulator was used successfully on open circuit scuba.

In 1878 the first practical scuba was developed by H.A. Fleuss. It was a closed-circuit unit and used 100% oxygen for breathing. Unfortunately Fleuss was not aware of the serious problem of oxygen poisoning caused by breathing 100% oxygen under pressure. It was not until many years later that maximum safe depths were established for use of 100% oxygen. During World War II Jacque-Yves Cousteau and Emile Gaguan combined an improved demand regulator and high pressure air tanks to create the first truly efficient and safe open circuit scuba. Their device was named the "Aqua-Lung" which today represents the most widely used and familiar diving equipment. With the development of the aqua lung numerous advances in diving

technology followed. Safe procedures and diving tables were established to avoid problems such as the bends, nitrogen narcosis and other ailments which will discussed under physiology in section 3.4. Safe limits and uses of air and different mixtures of gases were also developed as a result of the advances made in open and closed circuit scuba.

In addition, methods of decompression and saturation diving evolved which extended the diver's endurance at greater depths. Similar to the caisson air lock, deep diving systems were developed thereby increasing flexibility of continuous deep diving operations.

Having explained the basic evolution of the development of diving operations, one must briefly review underwater physics and physiology in order to understand the capabilities and restrictions placed on the various modern diving systems and platforms necessary to carry out underwater construction by the diver. These systems and their operations will be further discussed in detail.

3.3 UNDERWATER PHYSICS

3.3.1 General

The principles of physics provide the keystone in understanding the various diving techniques, procedures, and operation of diving equipment. They are also important concerning the effects that the underwater environment has on the human body. Knowledge of the behavior of gases, the principles of buoyancy, and the properties of sound, heat, and light underwater are particularly important to the diver and how he accomplishes work.

3.3.2 Kinetic Theory of Gases

The behavior of gases is especially important to the diver. Boyle's Law, Charles' Law and Dalton's Law are all necessary in calculating the effects of pressure, volume, and temperature on the diver as well as his equipment and tools. These gases laws are presented below:

Boyle's Law

$$PV=K$$

in which P = pressure

V = volume

K = a constant

Charles Law

$$V/T=K$$

in which T = temperature

P, V defined above

Daltons Law

$$P_{total} = PP_a + PP_b + PP_c + \ldots + PP_n$$

and

$$PP_a = P_{total} * \% \text{ Vol}_a / 100\%$$

where PP_n = partial pressures of various gases.

The total pressure (P_{total}) exerted by a mixture is equal to the sum of the pressures of each different gas making up the mixture. The pressure of each different gas is know as the partial pressure.

The General Gas Law is a combination of Boyle's Law and Charle's Law and is expressed as:

$$P_1(V_1)/T_1 = K = P_2(V_2)/T_2$$

P_1 = initial pressure (absolute)

V_1 = initial volume

T_1 = initial temperature (absolute)

P_2 = final pressure (absolute)

V_2 = final volume

T_2 = final temperature (absolute)

K= a constant

The importance of Boyle's Law can be demonstrated by a simple example using a balloon. The balloon can represent the divers lungs, air lift bags, or any gas filled device which can expand easily. If a 1 cubic foot volume balloon is submerged to a depth of 33 feet, the pressure outside the balloon will have doubled because of the addition of one atmosphere of pressure. The effect on the volume of the balloon will be a reduction to one half the original volume.

$$PV = K$$

at the surface: 1 (atm absolute) X 1 cubic foot =1

at 33 feet: 2 (atm absolute) X V = 1 V=0.5 cubic ft.

at 66 feet: 3 X V=1 V= 0.33 cubic ft.

atm = atmosphere

Figure 3 is a graphical display of the balloon at different depths (1 atm =33 FT). Notice that sudden changes in depth while in shallow water can be more dangerous than an equivalent change in depth while working in deeper water. For example, if a diver is ascending from deep water and does not vent air to offset the increasing volume in his suit or equipment his situation will become increasingly critical. The faster he ascends, the more the air expands, causing an even faster ascent until he pops to the surface, out of control, with possible serious injury due to decompression sickness or from colliding with a surface object. This condition is known as "blowing up". Two other examples of necessary calculations using the above gas equations are found in Appendix A which comes from the U.S. Navy Air Diving Manual.

Dalton's Law is significant because partial pressures of gases increase with increased depth. Therefore the slightest contamination of a breathing mixture with carbon dioxide or other contaminates could increase the toxic effects of the contaminate which normally would not be a problem at surface pressures. Figure 4 provides an example of Dalton's Law.

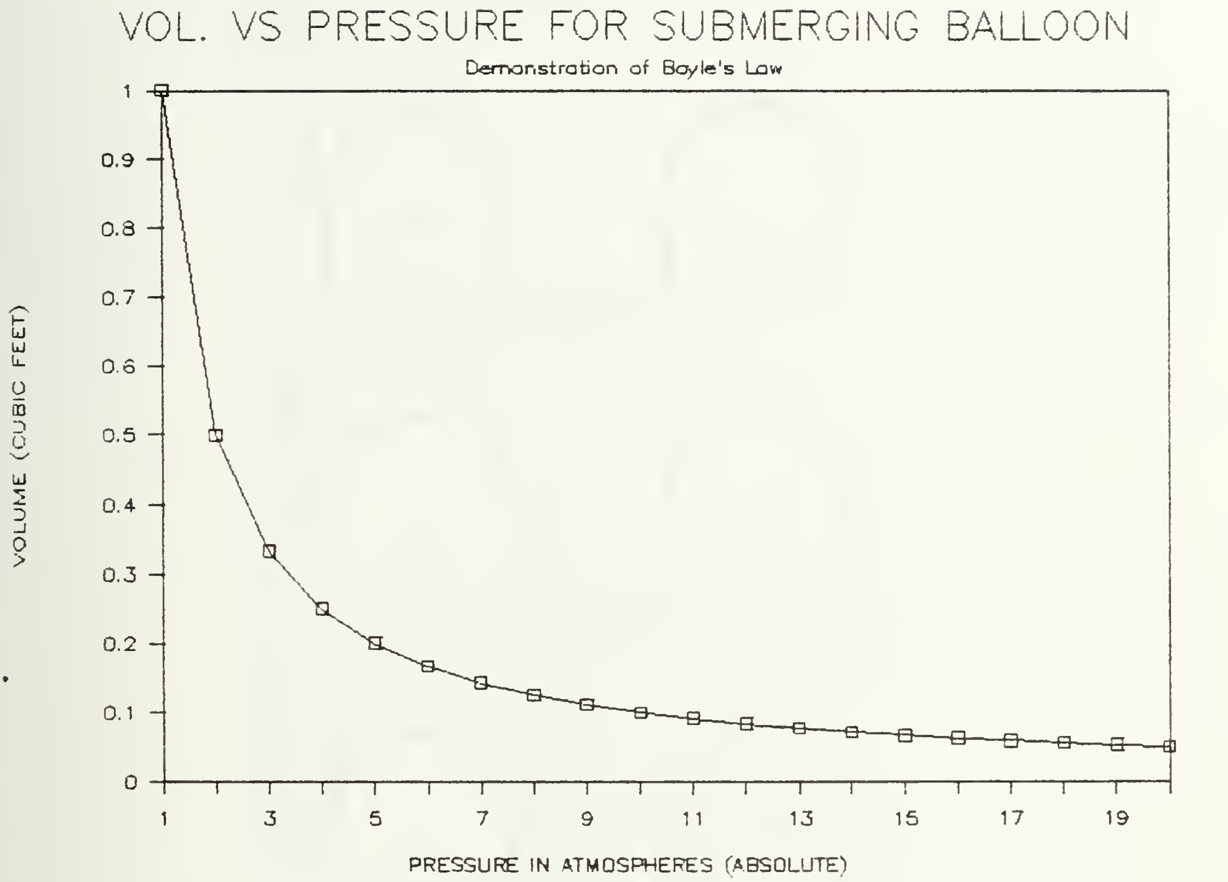
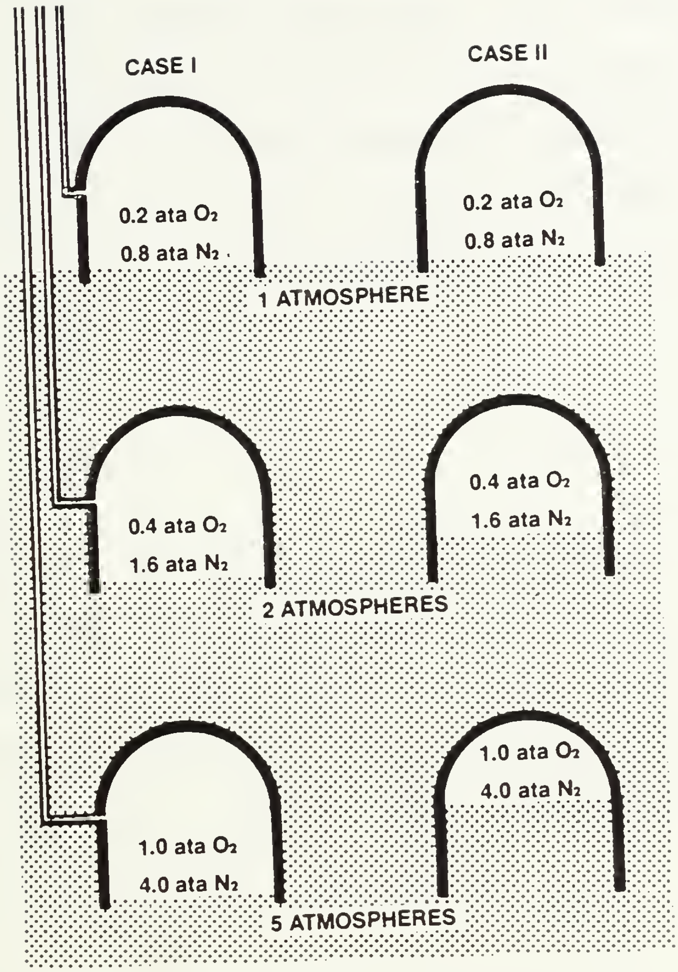


Figure 3 - Volume-Pressure Relationship of Submerging Balloon

Humidity is an important factor in a breathing mixture because proper amounts aid the diver's comfort by moistening body tissues. However too much humidity can also cause problems. Condensed water vapor can freeze and block air passageways in hoses and equipment, fog the diver's faceplate and corrode his equipment.



Partial Pressure:

In case I, similar to the situation in a diver's lungs, the partial pressures of the two gases (at constant volume) increase because of the addition of more gas molecules.

In case II, similar to an open-bottom diving bell, partial pressures of the two gases increase due to compression.

In both cases the sum of the partial pressures equals the hydrostatic pressure, and individual partial pressures increase in direct proportion to absolute pressure.

ata = atmosphere

Figure 4 - Partial Pressure of Gases in Relation to Depth
Source: (4:2-17)

Another relevant law of physics is Henry's Law which states that the amount of gas that will dissolve in a liquid at a given temperature is almost directly proportional to the partial pressure of that gas. This law is important in the physiological aspects of gases dissolving in the diver's bloodstream which will be discussed in section 3.4.

3.3.3. Buoyancy

Buoyancy is the force that makes objects float. It was first defined by the Greek mathematician Archimedes. He established that any object wholly or partly immersed in fluid is buoyed up by a force equal to the weight of the displaced fluid. This is known as Archimedes Principle and applies to all objects and all fluids.

Archimedes Principle is applied regularly in diving operations, underwater construction, and in marine salvage. The diver uses buoyancy compensation devices in the same way that a fish uses its air bladder to control buoyancy and vertical movement. In construction, divers apply the principle of buoyancy when using various types of lift bags to move heavy and bulky objects such as instrument arrays, support towers, anchors, pallets of construction materials, tools, equipment, and other objects. These lift bags range

in lift capacities from a few pounds to several tons. Therefore the principle of buoyancy is extremely important in marine and underwater operations. Lift bags and other buoyancy devices are discussed in more detail in section 4.3, Underwater Construction Tools.

3.3.4 Sound

Because water is fairly dense it is an excellent sound conductor and will transmit sound at a velocity of 3240 miles per hour. This is approximately four times faster than the speed of sound in the air. Underwater sound transmission was put to practical use during both WWI and WWII, in that communication was set up using bells which could be heard underwater up to 15 miles away. Also listening devices could detect enemy submarines and ships from far away.

However because sound travels so fast underwater, human ears cannot detect the direction of a sound source. This represents a disadvantage because the diver cannot locate objects by sound or detect sources of danger such as power boats or machinery.

Also variations in temperature, i.e., thermoclines, can cause refraction or bending of sound waves emanating from a sonar pulse. This causes problems for sonar operators attempting to obtain bearings on underwater objects and also interferes with communications between submarines and surface ships using underwater telephones (4:2-22).

It is impossible for divers to talk to one another. However, two divers wearing deep sea gear can put their helmets together and carry on a conversation because the metal helmets easily conduct the sound of their voices.

Because sound is a pressure wave and is readily conducted by water, shock waves from explosive charges can severely injure divers and structures with air cavities. Therefore underwater excavation, demolition, and cutting tools using explosive charges must be handled and used with care.

3.3.5 Heat

The main concern with heat transfer is keeping the diver's body temperature constant. Heat is conducted in three ways: conduction, convection, and radiation. "Several factors contribute to the problem of maintaining a diver's body temperature including-- suit compression, increased gas density, thermal conducting of breathing gases, and respiratory heat loss" (4:2-24). Normal rubber wet suits lose 60% of their insulating value at 33 feet and as a consequence a thicker rubber suit, a dry suit, or a hot water suit is needed for extended exposures at greater depths.

The thermal conductivity of a gas is directly proportional to its density. Therefore heat loss through gas insulating barriers and respiratory heat lost to the surroundings increases with depth. This situation is further aggravated when high thermal conductivity gases, such as helium-oxygen (7 times that of air), are used for

breathing. When breathing helium-oxygen, the respiratory heat loss alone increases from 10% of the body's heat generating capacity at 1 atmosphere, to 28% at 7 atmospheres, and to 50% at 21 atmospheres. Under these circumstances, insulating materials are insufficient to maintain body temperatures, and supplementary heat (usually hot water) must be supplied to the body surface and respiratory gas (4-24).

3.3.6 Light

Light behaves differently in water than in air for a number of reasons. Because the behavior of light affects the diver's visibility, and consequently his performance, it must be discussed. Underwater conditions which affect light are; diffusion, which scatters light, turbidity, which blocks light, absorption, which alters the color and intensity of light, and refraction, which bends light.

Light that penetrates the water decreases in intensity with depth, as light rays are scattered and absorbed. In clear water there is enough light for vision to about 300 feet (100 meters) but if the water is turbid, filled with impurities such as silt, algae, and chemical pollution, the

light is cut off much sooner. In these cases there may be enough light for vision but the particles block the sight of the diver. In severe cases, the diver may be blind the minute he goes below the surface, which is common in most harbors and rivers in urban areas.

Besides the change in intensity of light, the color quality of light also changes. The color of the water itself is influenced by many factors such as color of the sky (whether blue or dull gray), the quantity and nature of suspended particles such as sand or algae, and the depth of the water. Colors are affected by depth because wavelengths of visible light are progressively absorbed by the water and filtered out. In shallow water the red end of the light spectrum is filtered out and as depth increases yellow light disappears. At this point most objects take on a blue color and red objects appear black.

Refraction of light distorts the diver's vision. The bending of light causes an apparent displacement of objects. The effect is most pronounced for a diver wearing a face mask or helmet with a glass faceplate. The rays of light, reflected from an object, must first pass through the water, then the glass and then the air inside the face mask before reaching the lens of the eye. At each interface, as it enters a more or less dense medium, it will be refracted.

Because of refraction, objects underwater appear larger, and therefore closer, at a ratio of about four (apparent) to three (actual). The rock or wrench that seemed just within reach of the diver is actually about a foot further away and a fish 20 feet from the diver will seem to be only 15 feet away.

Because of the above characteristics of light, underwater construction requires supplemental lighting, especially at deep depths.

3.4 Diver Physiology

It is not within the scope of this paper to mention all the possible physical ailments or conditions that occur during diving. They are numerous and each one has a cause and effect relationship with the behavior of gases and pressure described in underwater physics. Therefore common physiology problems encountered are listed in Appendix B which are taken from the U.S. Navy Diving Manual. A diver employed in underwater operations and construction must be particularly aware of all physiological problems associated with diving so that he can avoid injuring himself. Performing underwater tasks can distract the diver from observing mandatory safety precautions and therefore he must be alert and knowledgeable about his own physiology.

3.5 TYPES OF DIVING APPARATUS

There are numerous varieties of diving apparatus which either use air or mixed gases for breathing. Some of the diving equipment has previously been mentioned. Because there are so many different types only the basic units will be addressed.

3.5.1 Air Diving Apparatus

Air diving operations use the following basic types of equipment:

1. Self contained underwater breathing apparatus (SCUBA)
2. Surface supplied diving equipment

Appendix C contains the general descriptions of a scuba apparatus and three surface supplied apparatuses. The normal and maximum limits for each are also provided. The appendix was taken from information contained in the U.S. Navy Diver's Manual.

When operating this equipment or any other air diving equipment, the diver must strictly adhere to standard air diving tables and allow for decompression times. This is necessary so the diver does not build up residual amounts

of dissolved nitrogen in the blood and get the bends (decompression sickness) when he surfaces. In certain cases divers are also restricted from flying in aircraft after dives because ambient pressure (cabin pressure) could cause nitrogen bubbles to form in the divers blood stream. Along the same line of logic, divers must follow different procedures when diving in elevated bodies of water such as mountain lakes and rivers.

The dive tables tell the diver the maximum time he can stay at a certain depth without making decompression stops. If a decompression dive is planned, the tables also tell the diver what stops he must make (depth and time) before he returns to the surface.

Decompression diving is very dangerous and is only done by professional divers with proper equipment and decompression chambers.

3.5.2. Mixed Gas Diving Apparatus

To avoid the problems with nitrogen in the blood stream associated with air diving, divers can breathe mixtures of inert gas and oxygen. The most prevalent mixture used is helium and oxygen. Because mixed gas diving operations involve complicated equipment, dive tables, and numerous safety procedures, it is beyond the scope of this paper to go into detail on the apparatus used.

The theoretical limit for mixed gas diving is 600 meters (2000 feet). Divers have performed underwater dry welding on pipeline construction at depths of 300 meters (984 feet). Divers performing test dry welds have been simulated in hyperbaric chambers to 350 meters. Therefore mixed gas diving can be used in development and construction on the continental shelf. In addition, these mixtures allow deep diving operations to last over extended periods of time in a hyperbaric environment. Diving under the above conditions is generally referred to as saturation diving.

CHAPTER FOUR

DIVER SUPPORTED CONSTRUCTION

4.1 GENERAL

The previous chapters reviewed the history of the development of diver operations, physics of the underwater environment, diver physiology, and types of diving apparatus. It can obviously be concluded from this knowledge that the underwater environment represents an extremely adverse, dangerous, and complex place to perform construction tasks. Therefore construction methods and procedures must follow strict safety guidelines to protect the diver and equipment.

This chapter will discuss frequently used underwater tools, general excavation, welding, and the role of prefabricated construction. The objective is to outline the basic capabilities of the diver's ability to perform underwater construction tasks. Operations planning and scheduling will be covered in the next chapter.

4.2 UNDERWATER TOOLS

Most commercially available tools used underwater are tools originally designed for land use with a few minor modifications, such as protective coatings of grease, epoxy paint, or chromium plate for corrosion resistance, or a special handle for adaptation to a manipulator arm on a submersible (manned or remote). However, the underwater environment generally degrades the performance of both the operator and the tool. For example, a simple task like driving a nail becomes significantly more difficult underwater because of limited visibility, resistance of the water to rapid movements, attenuation of the hammer blow at impact due to water viscosity, restrictions caused by the diving equipment and confined working spaces, and uncontrolled movement of the work piece or the diver.

However, because the cost of divers and diving systems are expensive, underwater tools or work systems are now being designed specifically for underwater applications and ease of use by the diver. This is extremely important because the diver is constantly under physical and psychological stress. The diver must also be free to make adjustments to his suit and hold himself and the tool steady in ocean currents.

For the purposes of this report, diving systems must be distinguished from work systems. A diving system is the total equipment necessary to bring a diver to a specific depth, to provide life support, and to return the diver to the surface. A work system is the equipment added to the diver to allow or enhance the capability to do work. Without a work system a diver is primarily only an observer. Diving systems and work systems also apply to manned submersibles which will briefly be reviewed later in this chapter.

Tools requiring only human energy from the diver to perform a task are known as hand tools and tools requiring additional energy are called power tools. Typical diver held hand tools and some of their uses are listed in Table 2.

Power tools can be classified according to their source of power, operation, function, etc. Power sources can be pneumatic, hydraulic, electric, or explosive. Typical underwater power tools and their uses are shown in Figures 5 through 13.

Table 2 - Typical Diver Handheld Tools

Tool	Use
Banding tools	Securing forms for cutting and welding
Bolt cutter	Shear rods, spikes, pins, wires
Chisel	Cutting
C-clamps	Securing objects temporarily
Drill	Drilling holes in wood
File	Enlarging holes
Grappling hook	Securing objects, anchoring
Hack saw	Cutting steel cable, heavy ropes, small pipe
Hammer	
Carpenter	Driving nails, small pins
Chipping	Cleaning growth and scale off welds, taking rock samples
Sledge	Driving stakes, spikes, pins
Handsaw	Cutting plank, timbers, piling
Knife	Cutting light line, rope
Pipe cutter	Cutting pipe
Pry bar	Moving or removing objects
Scraper	Cleaning surfaces
Shears, snips, and side cutters	Cutting line, small wires
Shovel	Moving small amounts of bottom soil
Standard rigging	Securing and moving objects
Taps and dies	Threading pipe or rod
Wrench	Turning nuts, bolts, pipe fittings

Source: (10:32)

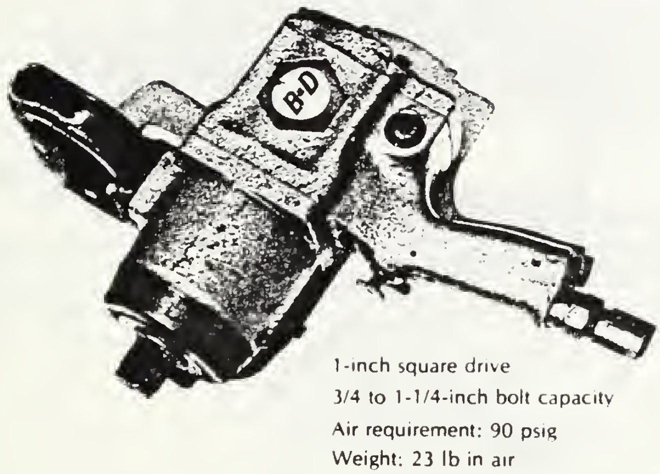


Figure 5 - Pneumatic-powered impact wrench.
Source: (10:35)

Figure 6 - Lightweight, diver-operated, hydraulic-powered impact wrench. (Courtesy of Stanley Hydraulic Tools, Milwaukie, Oregon.)

Source: (10:35)

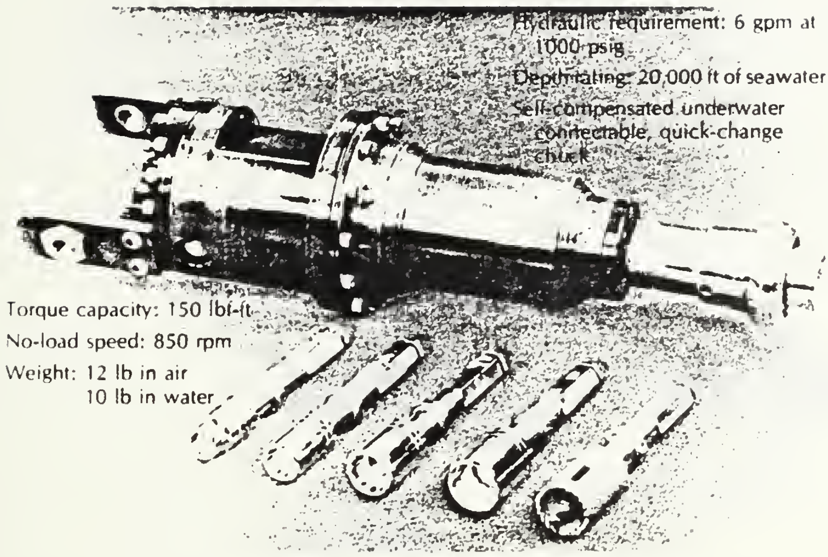


Figure 7 – Manipulator-operated, hydraulic-powered impact wrench.
Source: (10:37)

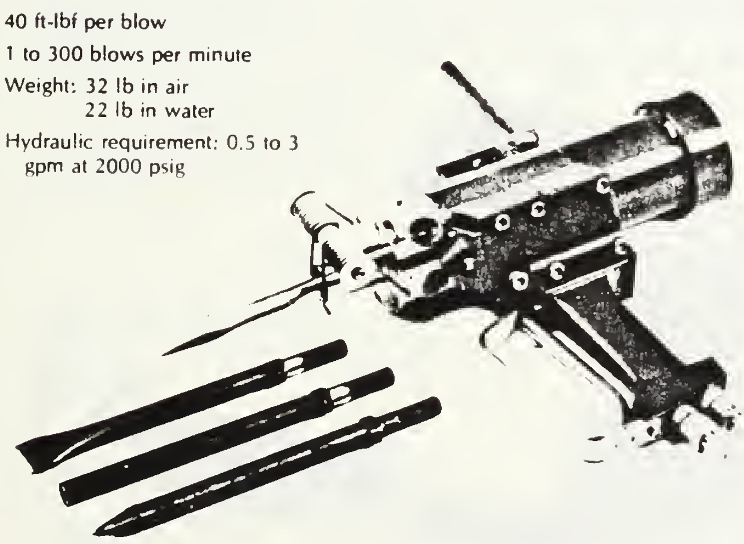


Figure 8 – Diver-operated linear impact tool.
Source: (10:37)

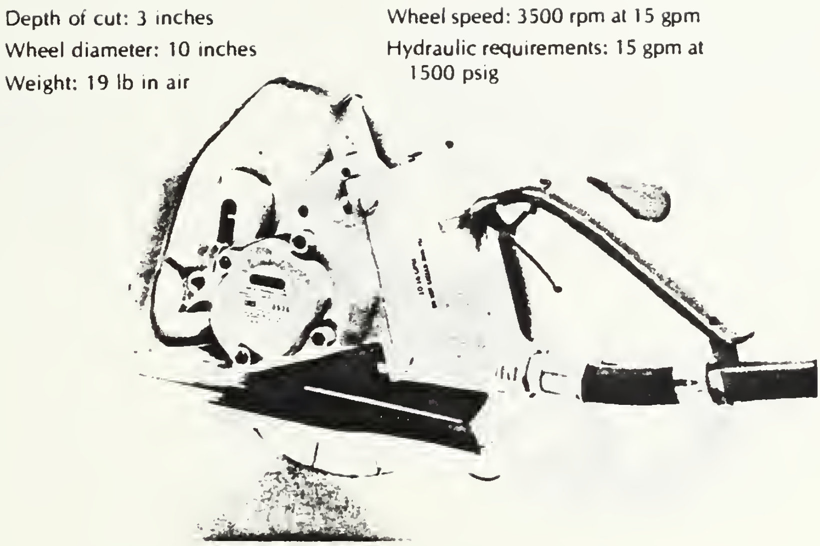


Figure 9 – Diver-operated abrasive cutoff saw. (Courtesy of Stanley Hydraulic Tools, Milwaukie, Oregon.)
Source: (10:40)

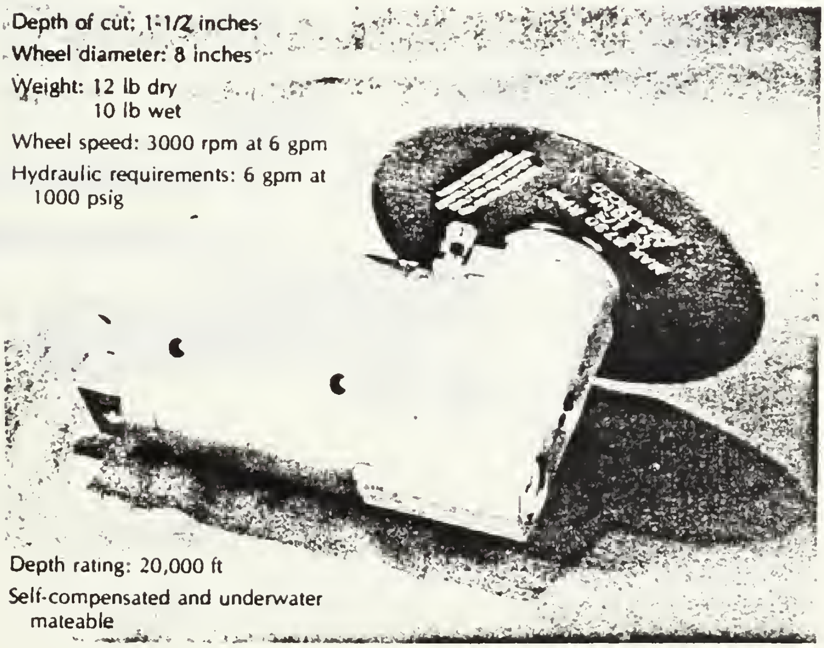


Figure 10 – Manipulator-operated abrasive cutoff saw.
Source: (10:40)

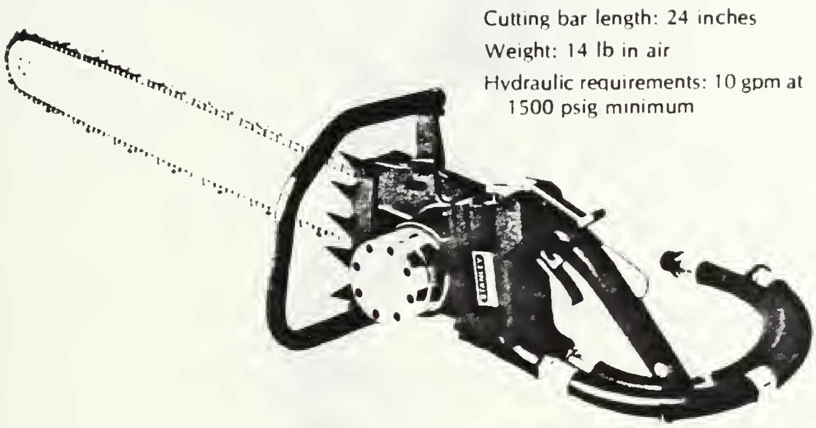


Figure 11 – Hydraulic-powered chain saw for diver use. (Courtesy of Stanley Hydraulic Tools, Milwaukie, Oregon.)

Source: (10:43)

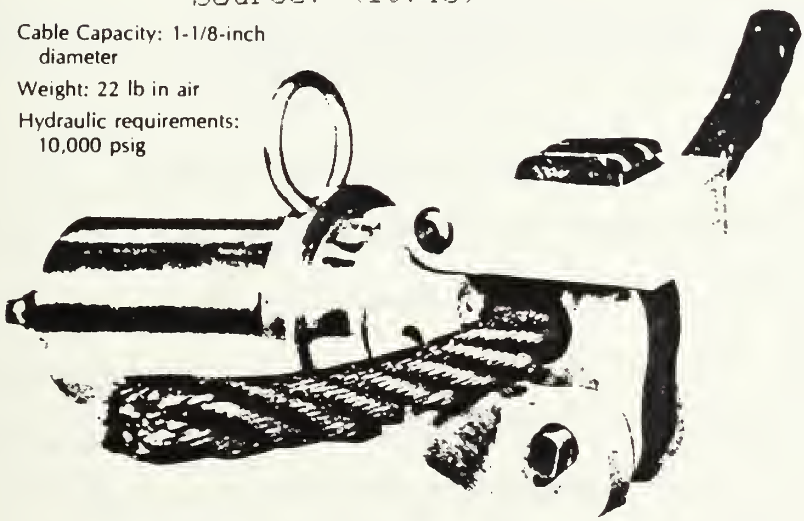


Figure 12 – Diver-operated, hydraulic-powered cable and bar cutter. (Courtesy of H. K. Porter Inc., Somerville, Massachusetts.)

Source: (10:36)

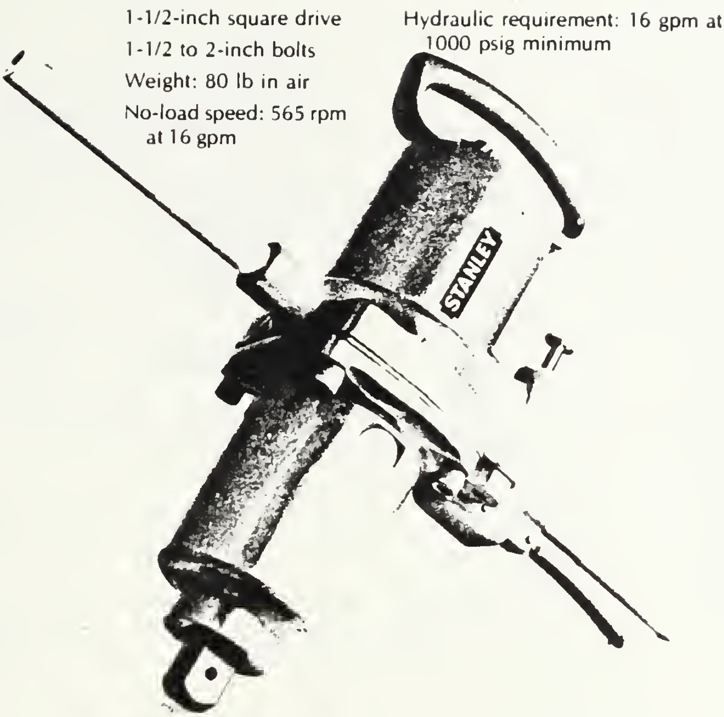


Figure 13 - Heavy-duty, diver-operated, hydraulic-powered impact wrench. (Courtesy of Stanley Hydraulic Tools, Milwaukie, Oregon.) Source: (10:43)

Many of these tools have been specifically designed for remote operated vehicle (ROV) manipulator arms and are part of a Work Systems Package developed for use with the U.S. Navy's Pontoon Implacement Vehicle (PIV), Alvin, and other submersibles. The Work Systems Package is similar a carry on tool shop enabling a submersible to complete a variety of jobs without returning to the surface. The submersible therefore can assist divers or work separately at greater depths. Table 3 lists the tools included in the package. The maximum operating depth of these tools is 20,000 feet.

Table 3

Summary of Work Systems Package tool suit.

Operating Mode	Power Head	Bits	Function	Capability
Rotary Hydraulic	High speed	Wire brush, Grinder, Cutoff wheel	Brush, Grind, Cut	125 lbf·in[a]
	Low speed	Drill, Tap, Die	Drill, Thread	275 lbf·in
	Reciprocating knife	—	Rope cut	2-inch dia.[b]
	Chipping hammer	Chisel	Chip	37 lbf, 21 strokes/s
	Impact wrench	Sockets	Bolt-unbolt	1,320 lbf·in
	Winch	—	Pull	1,000 lbf[c]
Linear Hydraulic	Jack	—	Jacking	19,000 lbf, 8-1/2 inch
	Spreader	—	Spreading	2,876 lbf. 13 inch
	Cable cutter	—	Cut cable	1-inch-dia. wire rope
Power Velocity	Cable cutter	—	Cut cable	1-1/4-inch-dia. wire rope
	Stud gun	Padeye	Attach padeye	1/8 to 5/8-inch-thick mild steel

a. Multiply by 0.113 to convert to N-m.
b. Multiply by 2.54 to convert to cm.
c. Multiply by 4.45 to convert to N.

Source: (10:31)

The operating depth for the power hand tools varies but the primary restriction is the practical length of pneumatic or hydraulic hose required. For ROV and other submersible applications the power comes from the submersible and no hose is required.

Since 1966, the U.S. Navy's Naval Civil Engineering Laboratory (NCEL) has been developing and evaluating experimental diver tool systems which use seawater hydraulics. Their most recently developed system consists of a diesel hydraulic power supply, a rotary impact wrench, rock drill, bandsaw, and a rotary propeller cleaning brush.

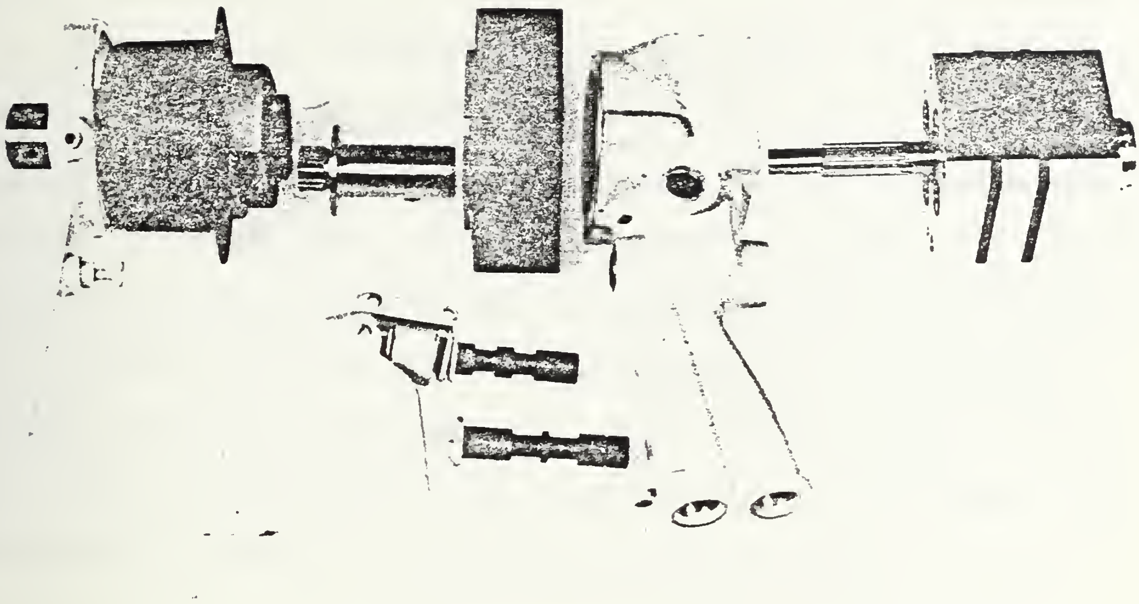
Normally these power tools use oil. Seawater hydraulic systems are advantageous because they eliminate the need for oil, have a single umbilical hose, are compatible with the environment, reduce maintenance and increase reliability, and reduce fire and health hazards. Oil systems have distinct disadvantages because the presence of oil poses a fire hazard to divers when in a hyperbaric environment (6:1).

Unique advantages of seawater hydraulic tools are:

1. Return hoses are not required, only a single small diameter hose which is flexible and easier to maneuver is attached. Drag imposed forces from ocean currents are significantly reduced.

2. The diver can connect and disconnect as well as assemble or disassemble the hydraulic components underwater.

3. Maintenance is reduced because the tool functions with seawater internally and externally. Figure 14 shows the seawater hydraulic impact wrench.



Impact wrench showing major subcomponents.

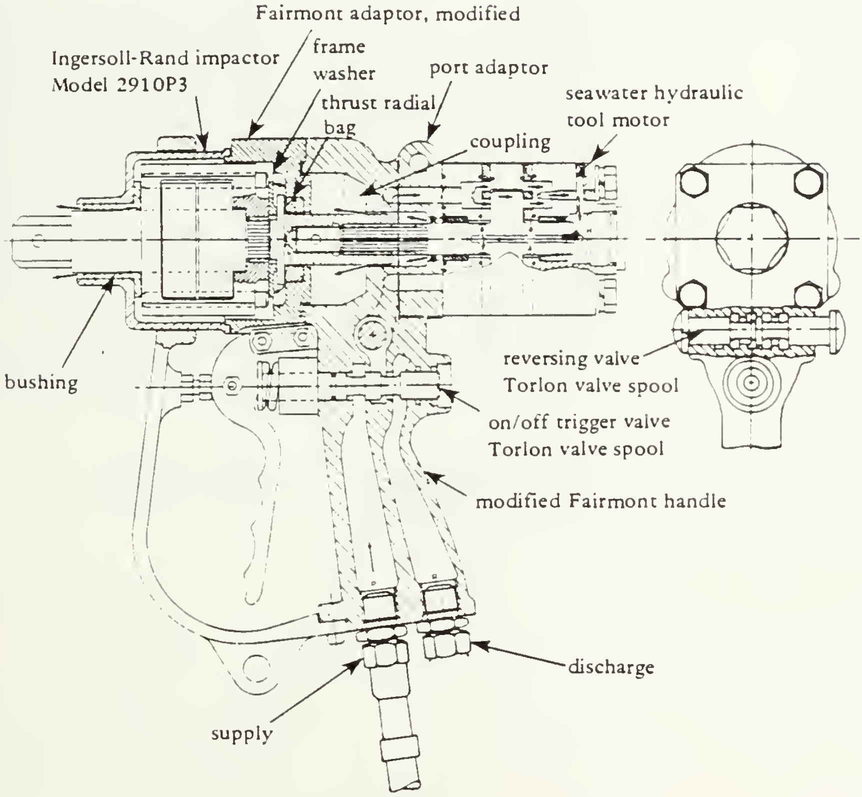


Figure 14 - Impact wrench showing seawater fluid path for bearing lubrication within the impact mechanism.
Source: (6:14)

Other tools developed by the NCEL are several geotechnical tools which are used by divers to aid engineers in site selection; calculating object embedment depths and breakout forces; designing foundations for marine structures such as piers, sewer outfalls, pipelines, and other structures that will interact with the seafloor. These tools can be operated in a water depth up to 130 feet and water temperatures from 28 degrees F to 90 degrees F. Figures 15 through 20 describe each tool (7:1).

IMPACT CORER – This tool takes a soil sample (core) up to 30 inches long and 1.5 inches in diameter in a clear Lexan plastic core tube. This core tube is supported by a frame which also contains a built-in impact hammer to drive the core tube into the soil. This corer has a piston in the core tube designed to stay at the seafloor surface and create a suction in the tube to help retrieve a relatively undisturbed soil sample. The core is sealed in the core tube and can be shipped to a geotechnical laboratory for testing. The tool is 47 inches long and weighs 16 pounds in seawater.

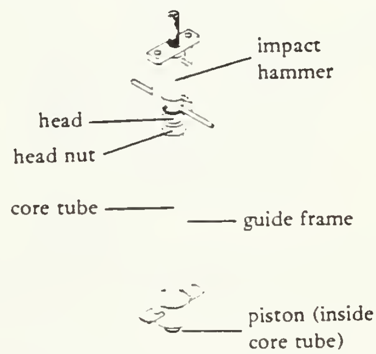


Figure 15 - Impact Corer
Source: (7:2)

MSPT (Miniature Standard Penetration Test) – This tool takes in-situ geotechnical data in cohesionless soils (sands). The tool consists of a shaft with a cone tip at the bottom and a hammer on a guide shaft on the top. The cone tip is set on the seafloor and the hammer raised to the top of the guide shaft. The hammer is then allowed to free-fall. The number of such hammer blows per 3-inch increment of penetration is counted. The hammer blow counts can be related to relative density. Data can be taken to a depth of 30 inches. The tool is 39 inches long (stored), 68 inches long extended, and weighs 14 pounds in seawater.

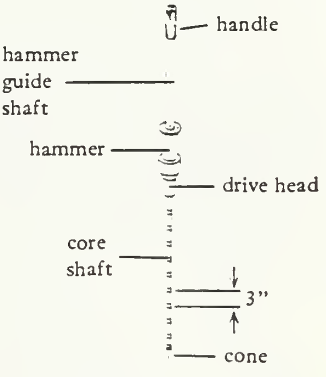


Figure 16 - Miniature Standard Penetration Test
Source: (7:2)

VANE SHEAR – This tool takes in-situ data in cohesive (clay-like) soils. The tool consists of three sizes of vanes attached to 30-inch shafts and a torque wrench that attaches to the top of the vane shafts. The torque wrench is used to rotate the vane in the soil until the soil fails in shear. The torque (in.-lb) required to cause this failure is measured and converted to vane shear strength (psi) through an equation. Data can be taken to a depth of 30 inches. The tool is 34 inches long and weighs 10 pounds in seawater.

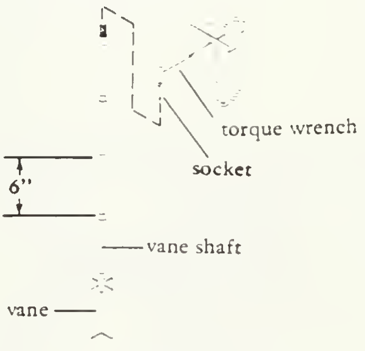


Figure 17 - Vane Shear
Source: (7:3)

ROCK CLASSIFIER – This tool produces data on the surficial strength of rock. The tool is a standard rock classifier used on land that has been fitted into an underwater housing. The rock classifier works by pressing a plunger against the rock surface; an internal hammer strikes and rebounds from the plunger. A rebound number is read off the classifier's scale and is related to axial compressive strength and the tangent modulus of the rock through charts. The tool is 19 inches long and weighs 3 pounds in seawater.

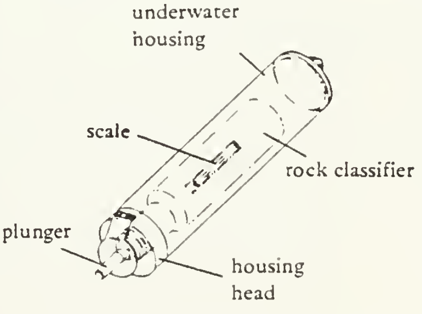


Figure 18 - Rock Classifier
Source: (7:3)

JET PROBE – This tool is used to determine sediment thickness by probing the seafloor to locate bedrock or other hard layers. It can also be used to verify subbottom profiler data. The tool consists of a 10-foot length of pipe with an on/off valve attached to a waterpump by 150 feet of water-hose. The tool is 11 feet long and weighs 15 pounds in seawater. The waterpump weighs 43 pounds.

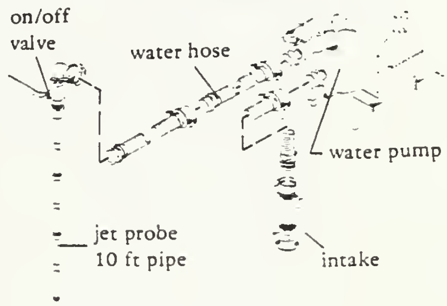


Figure 19 - Jet Probe
Source: (7:3)

VACUUM CORER – This tool takes an 8-foot core, 1.5 inches in diameter, that is fairly disturbed (due to the effect of the vacuum). The tool consists of an 8-foot clear Lexan plastic core tube and corer head attached to an eductor by a vacuum hose. Water is pumped through the eductor to create a suction in the vacuum hose and core tube. The vacuum helps the core tube penetrate the seafloor and allows divers to take an 8-foot core. The core can be sealed in the core tube and sent to a geotechnical laboratory for analysis. The type of analysis that can be done is limited by the amount of disturbance. The tool is 9 feet long and weighs 18 pounds in seawater.

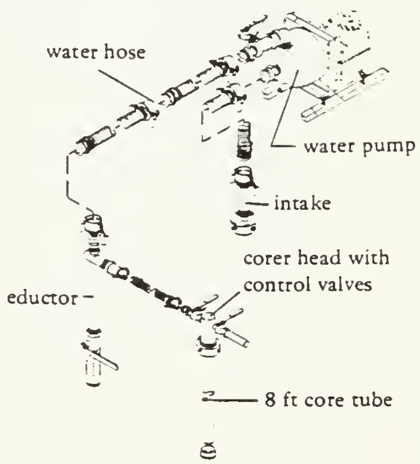


Figure 20 - Vacuum Corer
Source: (7:3)

NCEL also developed a diver operated grout dispensing gun, as shown in Figure 21, for installing rebar anchor bolts in soft, porous coral, concrete, and other materials. This tool pneumatically mixes the epoxy grouts underwater obtaining holding capacities in excess of 40,000 pounds for rebar grouted into concrete blocks. However proper installation techniques must be used to achieve these results. Figures 22 and 23 show the type of rebar tested and Figure 24 shows the results of several pullout tests all under the same conditions. It should be noted that two different divers were used and thus low pullout results were attributed to improper dispensing by diver 5 (8:24).

The tools discussed above do not provide a complete list of all that are available however they are the most frequently used for underwater construction. In the next three sections, moving weights, welding, and excavation will be discussed as well as the equipment and associated tools used for those tasks.

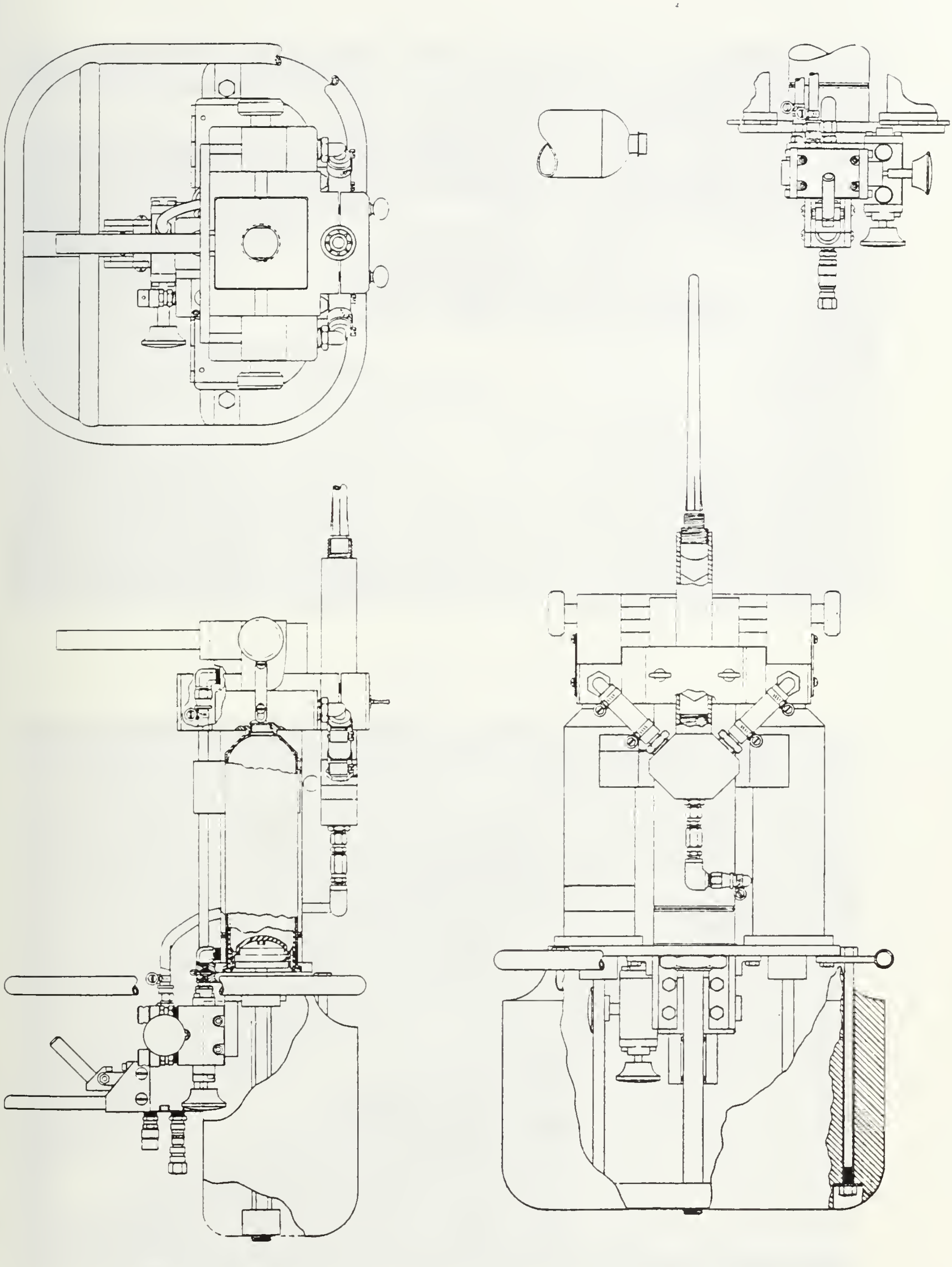


Figure 21 - Grout Dispensing Gun
Source: (8:54)

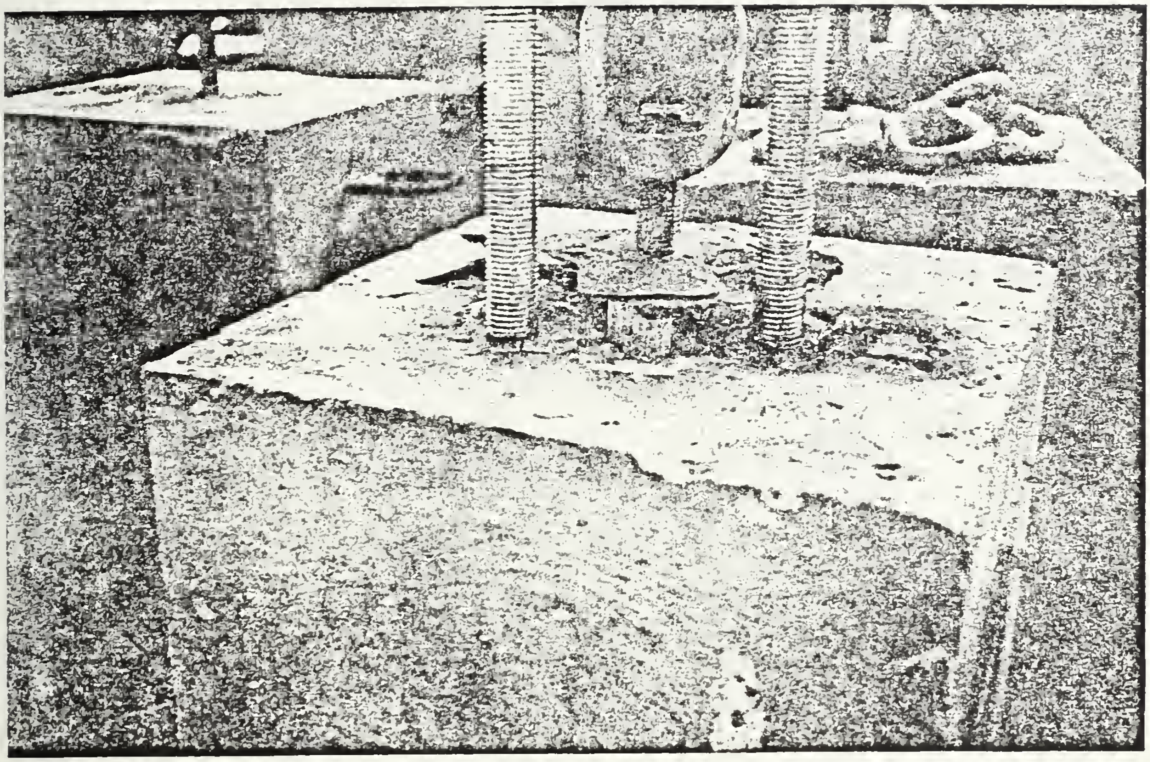


Figure 22 - Failed rebar fastener.
Source: (8:59)

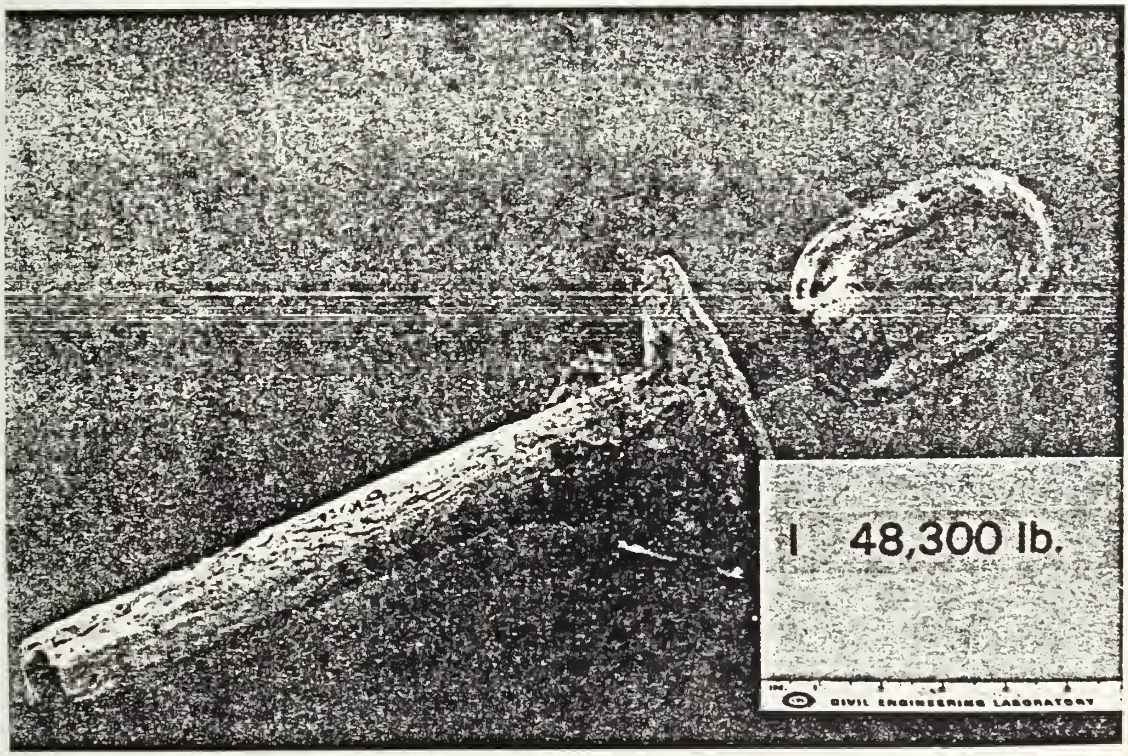


Figure 23 - Test fastener I.
Source: (8:59)

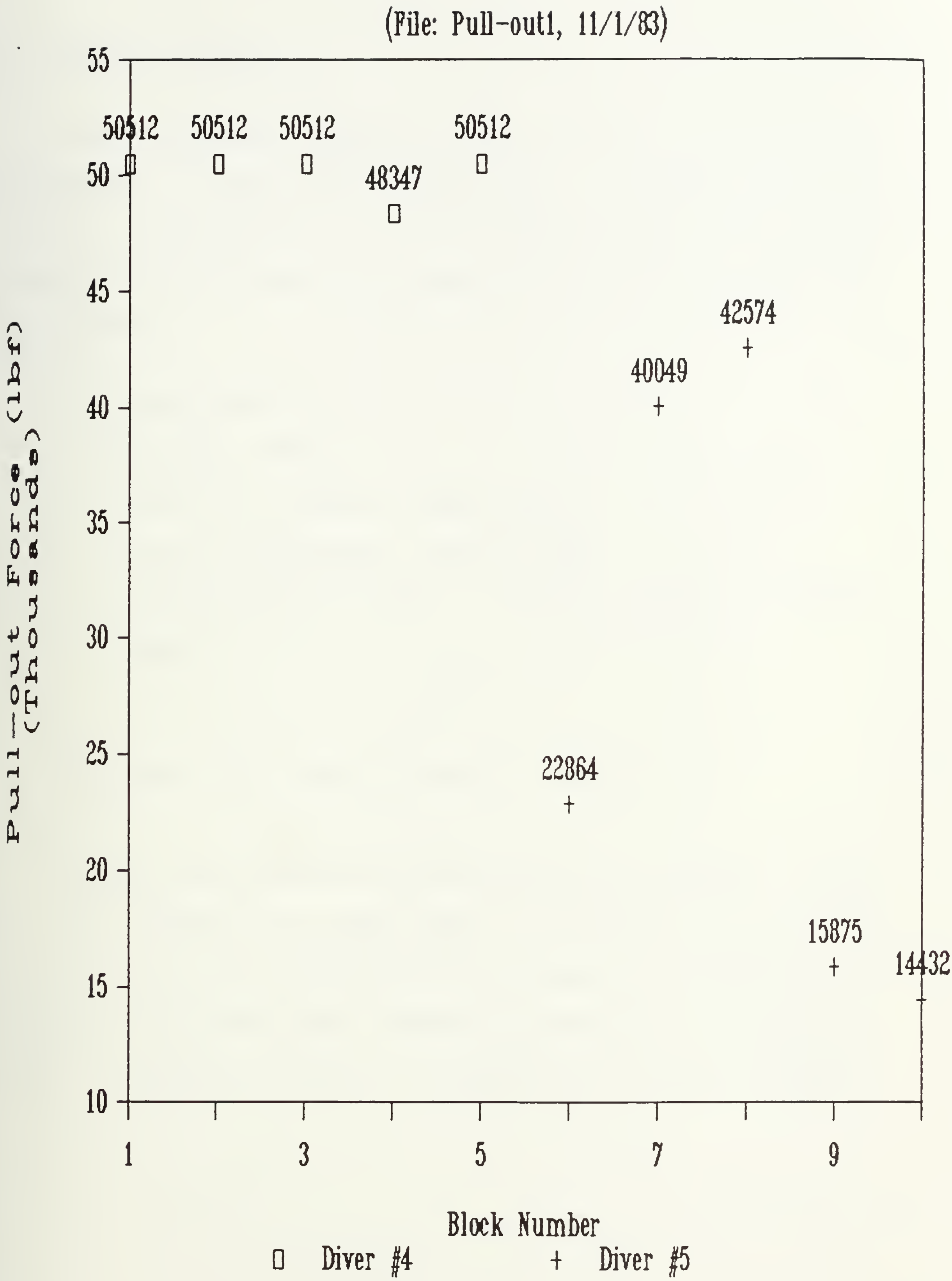


Figure 24 - Grouted Rebar Pullout Test
Source: (8:58)

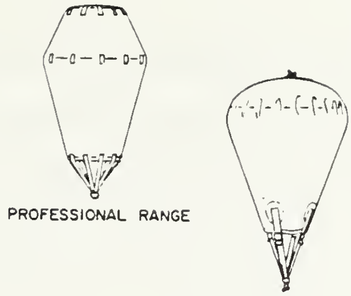
4.3 MOVING WEIGHTS

As previously discussed, Archimede's Principle is used frequently in underwater construction. Buoyant lift bags can act as underwater fork lifts moving heavy and bulky objects from one place to another. There are several lift bag systems:

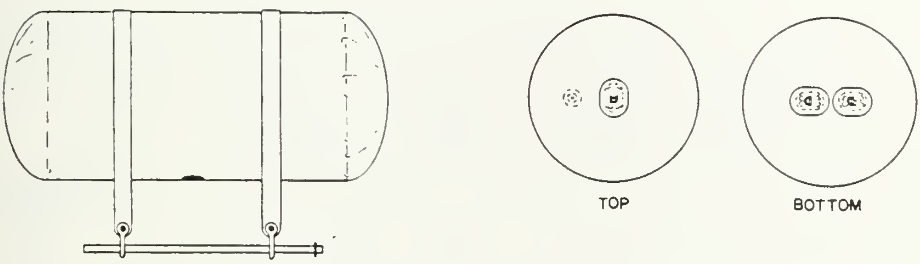
1. open bottom
2. closed bottom
3. variable buoyancy zipper bags
4. fixed displacement Kevlar bags
5. continuous automatic buoyancy control (CABCO) bags

The above lift bags are shown in Figure 25.

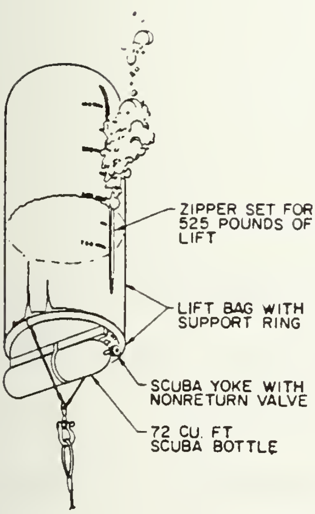
Typical open bottom lift bag sizes are listed in Table 4. The buoyancy of these bags is increased by admitting air into the bottom opening and decreased by exhausting air through the top-mounted, manually operated, air exhaust valve. Buoyancy however, is difficult to control because



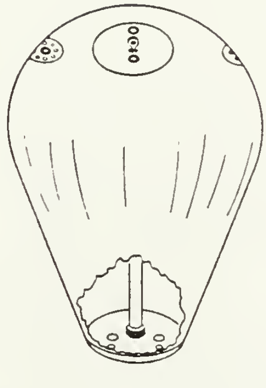
Open-bottom lift bags.



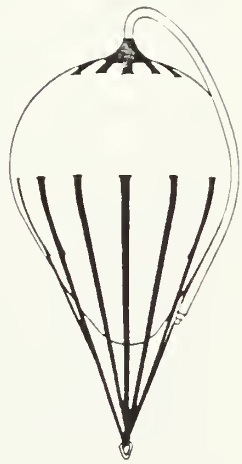
Closed-bottom lift bags.



Variable-buoyancy lift bag.



Fixed-displacement lift bag.



Continuous Automatic Buoyancy (CABCO) lift bag.

Figure 25 - Various Types of Buoyant Lift Bags
Source: (9:2-23)

of the on-off nature of the exhaust valves and the change in buoyancy (gas volume change) with depth. A slight ascent allows the bag to expand and buoyancy to increase which can cause the bag and its load to accelerate towards the surface. Conversely, a descent compresses the bag, causing a loss of buoyancy and acceleration downward.

Table 4 - Open-Bottom Lift Bag Available Sizes

Model	Lift Capacity (lb)	Overall Width (ft)	Overall Length (ft)	Shipping Weight (lb)
Minor Range				
M2	220	1.48	3.44	9
M5	550	1.97	4.26	10
M10	1,100	2.46	5.25	16
Professional Range				
Pr1	2,200	3.28	8.20	31
Pr1V	3,300	3.94	8.86	44
Pr2	4,400	4.43	8.86	57

Source: (9:2-23)

Closed bottom lift bags are used as salvage devices and as surface floats. They are available in a range of lift sizes from 220 to 11,000 pounds. The bags come with an air inlet for inflation and an over pressure relief valve to prevent rupture due to pressure imbalance during ascent. Buoyancy control is poor so they are mostly used for surface floating objects or when excessive buoyancy is needed.

Salvage pontoons are used as salvage lift devices only. They are not effective in construction applications due to their bulk and lack of buoyancy control. Inflation is generally controlled from the surface rather than by divers because of the lack of control and large buoyant forces involved.

Variable buoyancy lift bags have the open bottom design but use a full length vertical zipper to adjust the air volume of the bag. Ascent is controlled by allowing excess air to exhaust out the zipper hole. These bags are quite useful for controlled ascent with moderate payloads. However the bag is quite unstable in descent because air must be continually added to compensate for air volume changes due to compression. The air supply comes from an attached scuba bottle.

Fixed displacement bags are of the closed bottom design and employ a nonextendable, teardrop-shaped, Kevlar carcass coated with neoprene. Three lift sizes are available: 1.6 tons, 5 tons, and 10 tons. The diver controls the buoyancy using three valves: air inlet, water inlet, and water outlet. On ascent, expanding air exhausts through two relief valves and on descent displacement is held constant by adding air from an attached umbilical air hose. The system is reliable in service and can easily be controlled by a trained diver.

Continuous Automatic Buoyancy Control (CABCO) lift bags are open bottom, teardrop shaped lift balloons made of polyester fabric coated with polyvinyl chloride (PVC). Buoyancy is controlled by a flexible standpipe which penetrates the top and is affixed along the bag's side. By adjusting the height of the standpipe opening the diver can change the internal water level of the bag. Air is supplied to the bag from the surface and is allowed to vent through the standpipe similar to the zipper arrangement on the variable buoyancy lift bag. However (CABCO) bags are difficult to use and are not recommended for construction use. Various lifting capacities are available: 220 and 1,000 pounds and 2,5,and 10 tons (9:2-25).

For salvage of large objects on the continental shelf, the U.S. Navy developed a Large Object Salvage System (LOSS) which has a lifting capacity of 100 tons at a depth of 850 feet. The system is basically a large pontoon which uses a hydrazine liquid (N_2H_4) system to generate low density gases for pressure balancing and deballasting. The major features of the LOSS are shown in Figure 26.

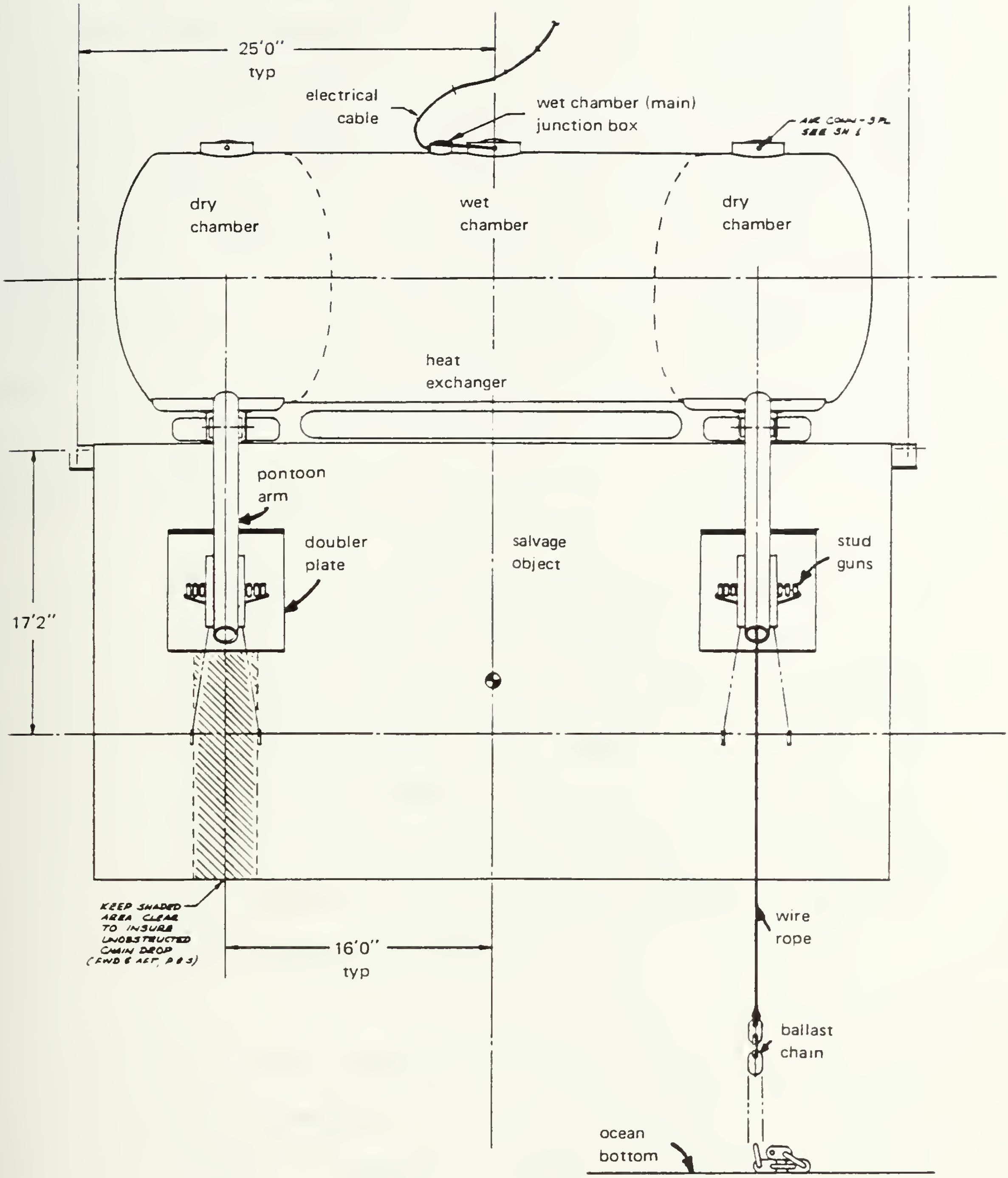


Figure 26 - Large Object Salvage System

4.4 WELDING AND CUTTING

Underwater welding and cutting have been used for many years in salvage, repair, and construction. The use of land welding techniques in open water is called "wet" welding. When a pressurized chamber is used to provide a dry environment around the weld zone or the entire work area, this is called "dry" welding. Dry welding techniques were first used in the mid 1960's. These techniques include the following (10:48):

1. Dry hyperbaric welding in an open-bottom chamber which encloses the weld area and the welder.
2. Minihabitat welding, a small chamber enclosing the work area and upper part of the welder/diver's body.
3. Portable dry box welding, a small transparent box sealed against the weld area where the water is displaced by welding gas.

There are other techniques used for underwater welding but they are experimental, such as firecracker welding and explosive welding. These will also be discussed in this section.

There are two kinds of underwater cutting techniques: mechanical and thermal. Mechanical cutting equipment was previously discussed such as the hydraulic chain saw, band saw, and abrasive cutoff saw. Cutting can also be accomplished with explosive hole punches and other explosive devices.

There are also many thermal cutting techniques which add to the efficiency and capabilities of cutting metal. Some thermal cutting techniques can cut nonconductive materials such as rock, concrete, coral, mastic, rope, and marine growth.

4.4.1 Wet Welding

Most wet welding is done during salvage and emergency repair using the conventional manual shielded metal arc process, also referred to as stick electrode welding, in which an electric arc is maintained between the work and a 12 to 15 inch long waterproof flux coated electrode. The arc burns inside a cavity formed within the flux covering which in turn burns slower than the metal rod of the electrode. The flux coating contains chemical compounds which are vaporized by the arc and the resulting gases shield the arc from the surrounding water (10:49).

The welder/diver uses a special electrode holder that is insulated from the water to protect him from electric shock. All electrical connections to the equipment are also insulated.

The advantages of wet welding are:

1. Welding can be done faster and at less cost than dry welding which requires an air pocket structure over the weld area.

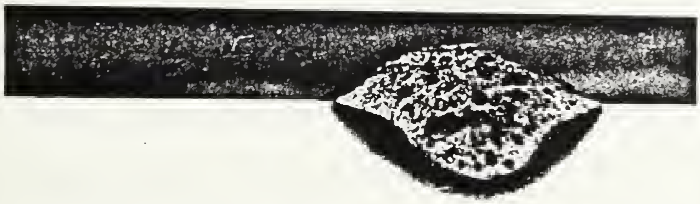
2. Electrode holders specifically designed for underwater welding are commercially available.

3. Standard welding machines and equipment can be used from the surface, allowing easy mobilization at remote job sites.

Wet welding is slow and requires great skill. When the welder/diver is changing an electrode he must signal the surface to break the circuit, replace the electrode, position the electrode for welding, and signal the surface again to close the circuit. Fillet welding a 6X6 inch lifting pad may take an hour, compared to 15 minutes on land. Since bottom time for divers is expensive, costs for wet welding operations are high.

Unless carefully performed by skilled divers, wet welds have questionable quality because the surrounding water quenches the material which reduces heat penetration and results in fusion defects. Tensile strength and ductility have also been found to be drastically reduced compared to similar joints made on land. The welds are likely to crack from rapid cooling and from the pick up of hydrogen due to hydrolysis caused by the arc. Therefore wet welding is usually restricted to mild and low carbon steels.

Conventional wet welding techniques have been tested to depths of up to 1200 feet. Test programs have shown that underwater welds can be achieved at greater depths by shielded metal arc welding. However, because of weld porosity this method gives generally poor results. Figure 27 shows cross sections of wet welds made at a simulated depth of 608 feet (10:52).



A. Straight Polarity

B. Reverse Polarity

Figure 27 - Cross sections of underwater arc welds made at a simulated depth of 680 ft (206 m).

Source: (10:53)

4.4.2 Dry Welding

Dry welding techniques are most often used on construction of submarine pipelines but are also used on external ship repairs where high quality welds are required. Provided that proper procedures are used, dry welds are better than wet welds because cooling rates are slower and hydrogen pickup is minimized. Therefore, high strength steels can be welded.

Hyperbaric chambers for dry welding are complex, costly, cumbersome, and usually require a large barge crane for handling. Minihabitats are less complex and easier to handle, but the diver must remain partially submerged within a confined working area. Portable dry boxes do not require lifting equipment but visibility is usually poor because of smoke and steam generated inside the box (10:53).

Besides stick electrodes, dry welding can be done with other conventional land techniques such as gas metal arc (GMA) or gas tungsten arc (GTA) welding systems. Both produce high quality welds, however they require more elaborate equipment. Stick electrodes may be unsuitable in certain manned chambers since smoke and fumes from the electrode coatings can quickly become intolerable.

In the GMA welding process, a small diameter wire electrode is fed continuously through the welding torch as it is consumed by the arc. Inert gases such as argon, helium, or carbon dioxide pass through the welding torch and out the nozzle surrounding and shielding the electrode from the existing atmosphere. All GMA equipment such as the welding gun, electrode feed spool, and controls are housed in the hyperbaric chamber while the power source remains on the surface.

GMA is the fastest arc welding process for dry welding underwater. On land, a welder can deposit 15 to 20 lb weld metal per hour with manual GMA as compared to 2 to 6 lb per hour using a stick electrode. In an underwater chamber, the welding rates would be about the same. However, GMA welding is difficult at diving depths because under the increased gas pressures the arc becomes more intense and the filler wire melts faster. With the increased pressure, the shielding gas becomes denser and flow rates of up to 10 times the surface rate may be required. Also, the excess molten metal can lead to such defects as overlap and improper fusion (10:54).

Like GMA welding, GTA welding uses shielding gas to protect the arc, however the electrode is a tungsten rod instead of a wire with a relatively low melting point. The arc does not melt the electrode but instead melts the edges of the metal pieces being joined. A bare wire is used as filler metal which is fed into the weld pool as needed.

GTA welding produces higher quality welds than GMA welds and have fewer difficulties under high pressures at diving depths. GTA is also the only proven way of making pipe welds underwater even though it is slower than GMA (10:54).

4.4.3 Experimental Welding Techniques

There are some experimental welding techniques used for underwater welding called firecracker welding and explosive welding. Firecracker welding, a version of shielded metal arc welding, uses a standard flux covered electrode placed in the groove of the metal pieces to be welded. The electrode is held in place by either a shaped metal block, magnet, or metal tape. The arc is then started at one end and allowed to travel unattended along the joint (See Figure 28). A diver is needed only to set and ignite the electrode; actual welding is accomplished without diver involvement. Figure 29 shows a typical weld resulting from the firecracker process. Important features of firecracker welding are :

1. There is no electrode manipulation, the size of the weld is determined by the electrode type and diameter.
2. Electrical current determines the welding speed.
3. Limited access areas can be effectively welded.
4. Because the diver can leave the area while the arc is running there is greater safety around hazardous areas.
5. Minimum welding experience is required to make consistent welds.
6. Welding can be achieved in low visibility.

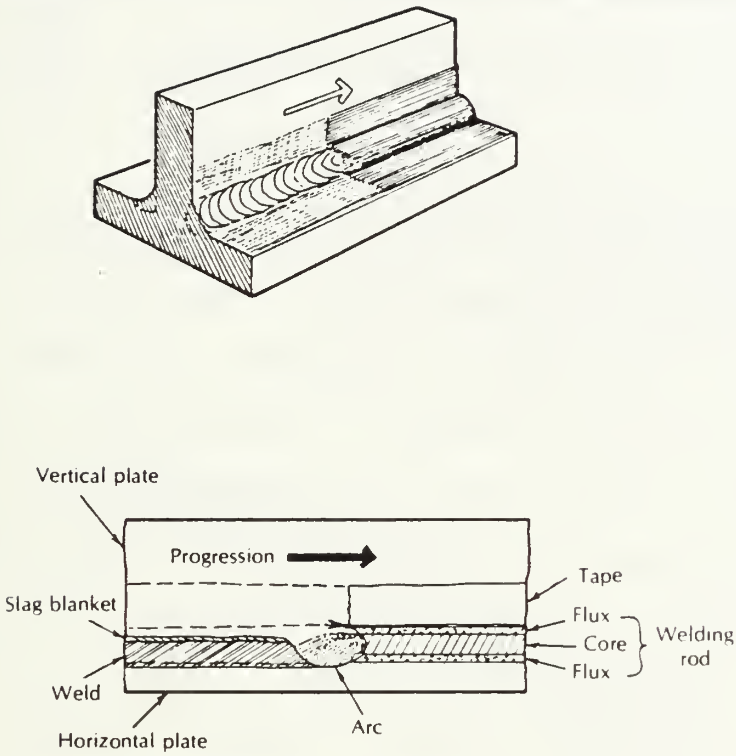


Figure 28 – Schematic of firecracker welding.
Source: (10:55)

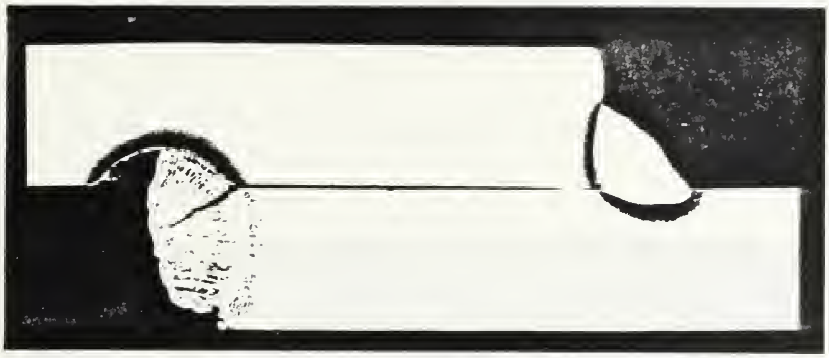


Figure 29 - Cross section of underwater firecracker weld.
Source: (10:56)

Sound welds using explosive welding techniques have been made to equivalent seawater depths of 20,000 feet. Explosive welds are especially applicable in making attachments to thick plates. Figure 30 shows an explosive housing for welding a padeye to a steel plate. The housing contains the padeye, sheet explosives, detonating cap, and provides a waterproof, gas filled chamber on the surface of the underwater object. The surface to be welded must be dry, free of debris and rust. The unit is held in position with two permanent magnets on either side of the housing. When the explosives in the housing are detonated, the wings of the padeye are forced against the surface of the object at extremely high, controlled velocities. The resulting impact metallurgically bonds the padeye wings to the surface of the steel plate. The explosive padeye shown weighs 20 lbs and when correctly bonded has a lifting capacity of 5,000 lbs (10:56).

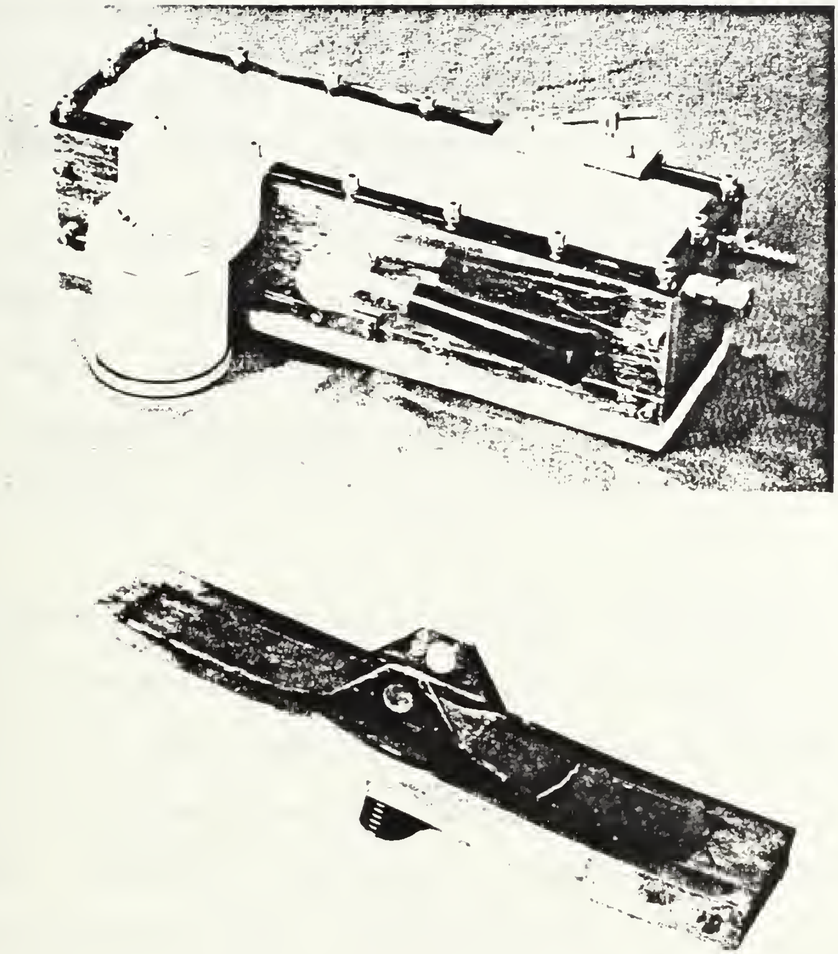


Figure 30 - Explosively bonded padeye for diver use.
Source: (10:57)

4.4.4 Cutting

Cutting materials underwater is usually required for maintenance and repair work but will no doubt be a future requirement for expansion or additions to underwater pipelines and submerged facilities. Currently, cutting is accomplished by thermal, mechanical and explosive means.

Various types of thermal cutting processes have been used underwater such as gas cutting, oxygen-arc cutting, thermal lance, thermal arc, arc plasma and the pyrotechnic torch. Table 5 lists most of these techniques and each of their advantages.

Plasma arc, pyrotechnic torches, and thermal lances are mostly experimental techniques. A typical thermal lance is a 10 foot long 3/8 inch diameter pipe packed with rods of different metal alloys, such as aluminum, magnesium, thermite, and steel. High pressure oxygen is forced through the pipe. Once the end is ignited it burns with tremendous heat, 10,000 degrees C. This typical lance lasts about 6 minutes but will burn or melt almost anything, steel, nonferrous metals, rock, and concrete. However because of its length, handling and cutting is extremely awkward. The lance has a high rate of oxygen consumption and is presently being developed to operate down to 100 meters of depth (1:44).

Table 5 – Advantages of various cutting processes. (Adapted from *Underwater Cutting and Welding Manual*, U.S. Naval Ship System Command, 1969.)

Oxygen-Arc Process, Tubular Steel Cutting Electrodes

- Preheating is not required
- Flame adjustments are unnecessary
- Applicable to all metal thicknesses
- Overlapped plates can be cut
- Holidays (skips) can be cut
- Only one gas (oxygen) is needed
- Torches are lightweight
- Less training and skill are required
- Higher cutting rates on thin metal

Oxygen-Arc Process, Ceramic Cutting Electrodes

- Low burnoff rate, long life
- Short length provides easier access in confined spaces
- Light weight improves transportability

Shielded Metal-Arc Process

- Preheating is not required
- Cuts ferrous and nonferrous metals
- Fuel gases and oxygen are not required
- Standard electrode holders can be used in an emergency if properly adapted

Oxy-Hydrogen Process

- Electricity is not required for cutting
- Nonmetallic materials can be severed
- Insulated diving equipment is unnecessary
- Power generators are not required
- There are no ground connections
- Higher cutting rates on thick metal

Oxy-acetylene

- High-flame temperature
- Electricity is not required for cutting
- Insulated diving equipment is unnecessary
- Power generators are not required
- Nonmetallic materials can be severed

Plasma-Arc

- Potentially high cutting rates
- Fuel gases and oxygen are not required
- Cuts ferrous and nonferrous materials

Pyrotechnics

- High cutting rate
- Cuts ferrous and nonferrous metals
- Fuel gases and oxygen are not required

Explosives

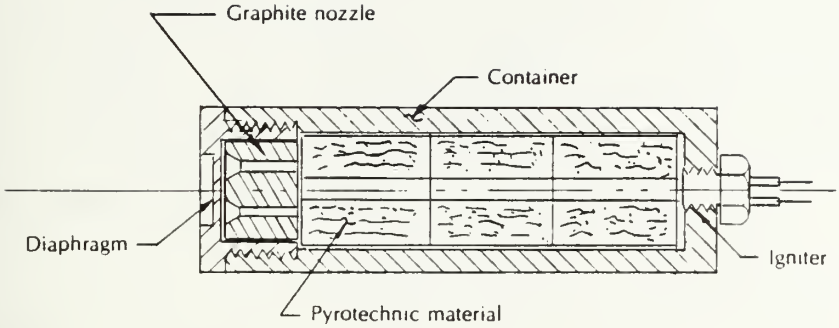
- Multiple cuts can be made simultaneously
- High cutting rates
- Fuel gases and oxygen are not required
- Electricity is not required

Source: (10:59)

The thermal arc method is the same as the thermal lance but uses a tough flexible plastic covered cable which comes in 100 foot lengths. It is easier to use and lasts longer.

The plasma arc method uses a tungsten rod cathode and a water cooled copper nozzle anode positioned in an insulated body through which gas is fed. The system is set up by the diver but is remotely controlled. Cutting temperatures exceeding 30,000 degree C can be achieved which is three times the temperature of a conventional welding arc (1:45).

Pyrotechnic torches can be used to cut heavy steel plate, chain, cable, or pipe. A typical pyrotechnic torch is shown in Figure 31. The torch uses exothermic powder with nickel, aluminum, iron oxide, and a fluorocarbon in the mixture. When ignited, the resultant molten metals and oxides are ejected at high velocity through a nozzle creating a hot cutting jet. Even though cutting capability decreases with depth, successful cuts have been made in excess of 3000 foot depths.



Cross section of pyrotechnic cutting torch.

1-⅝-inch-diameter (4.1 cm) wire rope cut with pyrotechnic torch.

Figure 31 - Pyrotechnic Torch
Source: (10:66)

Underwater mechanical cutting tools have been previously introduced. There are also mechanical cutting tools which utilize explosives for power and are effective at great depths. For example Figure 32 shows an explosive actuated underwater cable cutter which is commercially available with an operating depth of 20,000 feet. Figures 33 and 34 show an explosive hole punch designed to cut a 4 inch diameter hole in a 2 inch thick steel plate at depths of 1000 feet. This tool is installed by the diver, held in place with magnets, and then remotely actuated.

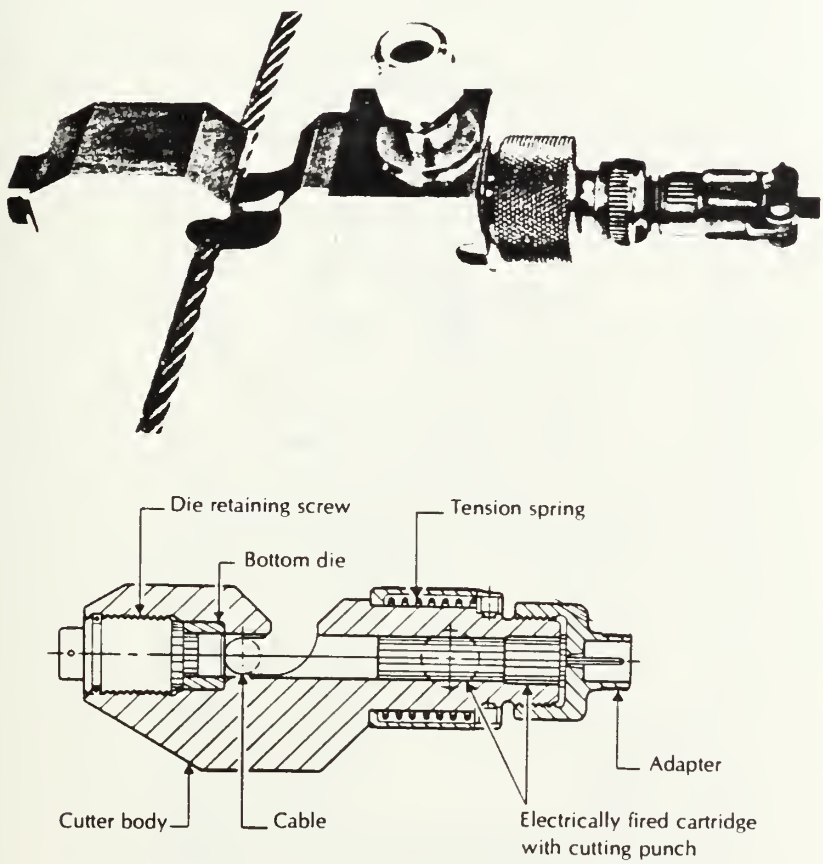


Figure 32 - Explosively actuated underwater cable cutter. (Courtesy of Mine Safety Appliances Co., Pittsburgh, Pennsylvania.)

Source: (10:45)

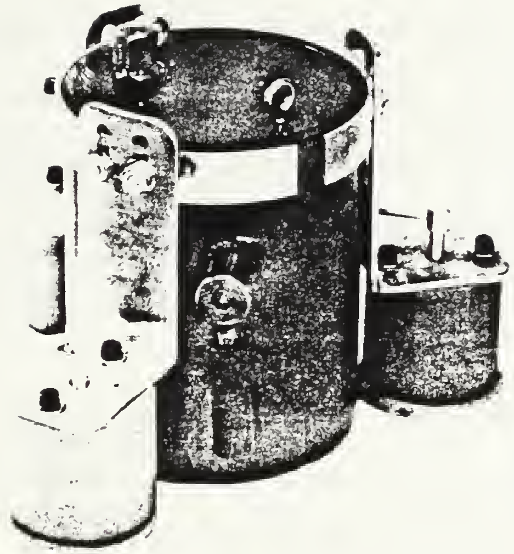


Figure 33 - Explosive hole punch.
Source: (10:68)

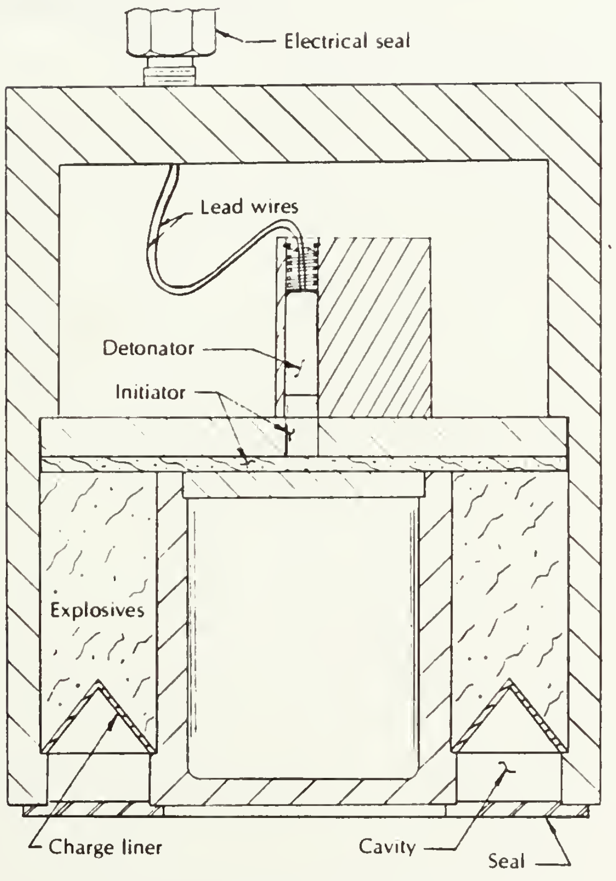


Figure 34 - Cross section of explosive hole punch.
Source: (10:70)

Explosives and shaped charges by themselves can be effective tools for cutting almost any type of material. Most of the early uses of explosive cutting were for demolition work, cleaning submerged rocks, underwater excavation, and demolition of cofferdams (10:67).

Explosive underwater cutting methods began with strings of explosives destroying an object within a localized area. Localized blasting is now accomplished by shaped charges containing metal liners which act as cutting projectiles. Shaped charges can be used for virtually any underwater cutting application.

4.5 EXCAVATION

Many construction tasks require the removal of seafloor sand and sediment for the emplacement, inspection and repair of pier pilings, pipelines, and cable systems. Divers can perform seabed excavation by air lifting, jetting, dredging, and controlled blasting. The best method for any particular situation depends on a number of factors including (9:2-26):

1. The nature of the seabed material to be excavated.
2. Water depth
3. The horizontal distance the excavated material must be moved.
4. The vertical distance the excavated material must be lifted.
5. The size of excavation and type (trench excavation, local excavation, general excavation, etc.).
6. The nature of local currents and wave action.
7. The size and type of surface support equipment used.
8. The portability and weight of excavation equipment.

Table 6 provides general guidance on the suitability of using various excavation methods as a function of several criteria. Not all situations are included and sound judgement must be exercised for selection of the optimum method.

Table 6 – Suitability of Underwater Excavation Methods

Excavation Factor	Excavation Method			
	Air Lift	Jet	Dredge	Blasting
Type of seabed material	mud, sand, silt, clay, cobbles	mud, sand, silt, clay	mud, sand silt, clay	coral, rock
Water depth	25 to 75 ft	unlimited	unlimited	unlimited
Horizontal distance material moved	short	short	short to long	short
Vertical distance material moved	short to long	short	short to medium	short
Quantity of material excavated	small to large	small to medium	small to medium	small to large
Local current	not required	required	not required	not required
Topside equipment required	compressor	pump	pump	hydraulic power unit
Shipping space/weight	large	small	medium	large

Source: (9:2-23)

A description of each method listed in Table 6 is provided below, except for controlled blasting which is not within the scope of this report. Controlled blasting is not specifically oriented to tools except the shaped explosive charges which have already been examined.

4.5.1 Air Lifting

Excavation by air lifting uses a very simple device consisting of a hollow discharge pipe and an air chamber. Compressed air enters the pipe through the air chamber which is 20 to 30 inches from the intake end. The air bubbles combine with the water in the pipe creating a mixture that is less dense than the water outside the pipe. The lower density water flows up the pipe to the surface and creates a suction at the inlet (see Figure 35). The amount of material lifted will depend upon the size of the air lift, submerged depth, air pressure and flow rate used, and the discharge head. Table 7 is a selection guide for air lift discharge pipes and air supply requirements.

Operation of the air lift simply involves turning on the air compressor and air control valve, then submerging the intake into the seabed material. Seabed material flows into the inlet almost as soon as the low density fluid in the discharge pipe rises. Experimentation is usually required to determine the proper air flow required for maximum efficiency. The air pressure delivered to the air chamber is relatively unimportant, but it must be greater than the water pressure at the depth which excavation is performed.

Air lift devices can be from 10 to 70 feet long but are relatively inefficient for lengths less than 30 feet. The discharge end of the air lift should be kept as close to the surface as possible for maximum efficiency.

The disadvantage of the air lift is that discharged material is relatively close to the intake point which may result in some of the material settling back into the excavation area. Therefore the discharge should be positioned down current so the material can be carried away.

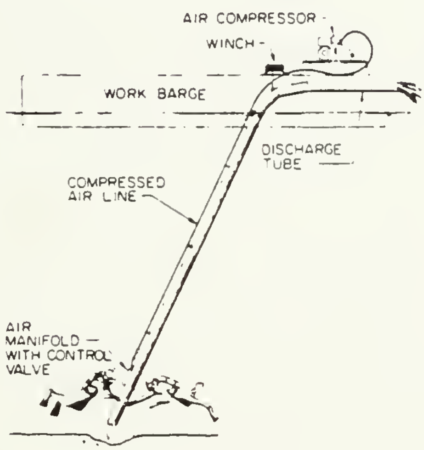


Figure 35 - Diver Operated Air Lift Device
Source: (9:2-27)

Table 7 – Selection Guide for Air Lift Discharge Pipe and Air Line

Diameter of Discharge Pipe (in.)	Diameter of Compressed Air Line (in.)	Discharge Rate (gpm)	Air (cfm)
3	0.50	50-75	15-40
4	0.75	90-150	20-65
6	1.25	210-450	50-200
10	2.00	600-900	150-400
12	2.00	900-1,000	200-550

Source: (9:2-23)

4.5.2 Jetting

Jetting is useful in excavation of seabed soils for the burial of cables, pipelines, and for installing instrument arrays and structural piles. It is usually accomplished by supplying pressurized water from a surface pump to an underwater hose and nozzle. A variety of jetting mandrels and nozzles can be used, depending on the work required and desired flow characteristics, such as width of jet and jet velocity.

4.5.2.1 General Excavation

For general excavation, divers can use high velocity jets to remove vast quantities of mud, sand, or silt. The diver using the jet must continually fight the back thrust from the jet nozzle, however special nozzles are available that have balancing jets to reduce or eliminate back thrust as shown in Figure 36. A pump flow rate of 100 gallons per minute and a discharge pressure between 50 and 150 psi above the ambient pressure is adequate for this type of jetting operation.

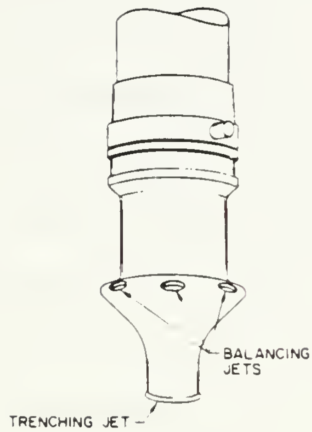


Figure 36 - Jetting Nozzle
Source: (9:2-29)

When there is a large mound of material to be moved, the diver starts at the top and washes it away. Starting at the bottom of the mound is not effective. A good procedure is to use sharp bursts of the jet in between raising the jet above the work area and directing it horizontally. This way the material will be removed from the area without reducing visibility by clouding the work area. This method is most efficient if there is a fairly strong current to carry away the jetted material from the excavation area. The diver should of course be positioned up current.

4.5.2.2 Cable and Pipeline Burial

Cable and pipeline burial by jetting can be done using two different techniques. First, large jets are used to erode and displace the seabed soil leaving an open trench. This method works well in many slightly or moderately consolidated cohesive soils (mud) as well as some noncohesive (sandy) materials. The cable or pipeline is laid along a planned route and a trench is then jetted underneath or beside it. The second method, called fluidization, is used for sandy soils (noncohesive). Many small jets are mounted on the leading edge of a plow like blade. These small jets erode and suspend the sand in front of the blade. The cable or pipe is then fed into the jetted area by a guide chute. The reduced density of the sandy soil allows the cable or pipe to sink in and become buried. Typically the pump used for fluidization should have a flow rate of at least 500 gallons per minute at a pressure of between 100 to 150 psi.

4.5.2.3. Tube and Structural Pile Installation

The jetting technique can be used for installing tubes for mounting instruments and structural piles. Figure 37 shows a typical jetting stand and jetting mandrel tube apparatus. Structural piles may have a jet pipe built into the center of the pile. A water hose is connected to the top of the pile and the open end of the pile serves as the nozzle. For all types of piles, a jet pipe can be placed alongside the pile beyond the end of the pile. The pile and jet pipe are lowered together as the jet displaces the soil below. Usually the jet is removed before the pile reaches the specified penetration depth and a hammer is then used to drive the pile to achieve an adequate bearing capacity. This method however, is only effective in noncohesive (sandy) soils.

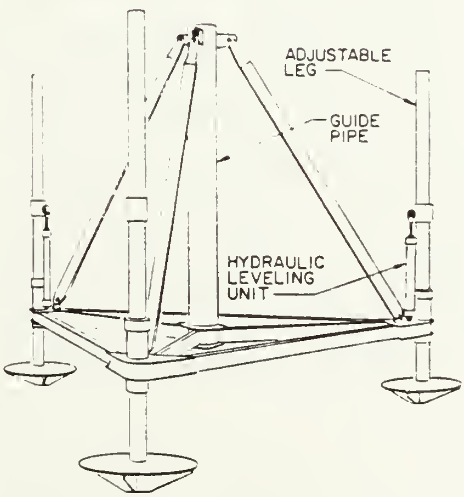


Figure 37 - Jetting Stand
Source: (9:6-23)

The installation of the tubes or structural piles is directed by divers equipped with two way communication. They set up the jetting stand and coordinate the operation with the required surface support, crane and pump crews.

4.5.2.4 Dredging

Underwater dredging is a useful technique for moving large quantities of soft seabed material in cases where the water is too shallow for an air lift to be effective and where the material does not have to be moved too far above the intake point (9:2-30). Figure 38 shows a typical diver operated dredge. It consists of a pipe with a 30 degree angle bend near the intake at which a water jet is connected. The jet moves water in the pipe and creates a suction at the intake. A 6 inch pipe dredge with a 200 gallon per minute pump can excavate as much as 10 cubic yards of loose gravel, mud, and sand per hour (9:2-31). The diver operated dredge can be held in place and repositioned by the diver. The reaction forces are low and buoyancy is normally not required (11:12).

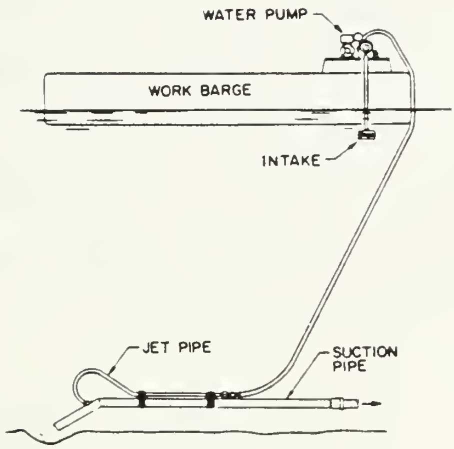


Figure 38 - Diver Operated Dredge
Source: (9:2-30)

CHAPTER FIVE

OPERATIONS PLANNING AND SCHEDULING

5.1 GENERAL

Attempting an underwater construction project is one of the most complex ventures involving construction. A project manager and construction team must predict, estimate, and account for a much greater number of variables affecting the project as compared to a similar land based one. These unknowns include but are not limited to :

1. weather
2. sea state
3. currents, tides
4. visibility
5. operating depth
6. bottom conditions
7. pollution
8. dangerous marine animals
9. water temperature
10. diving technique
11. ship traffic
12. extensive logistics

The underwater construction contractor must be a highly technical professional and must be competent in underwater and ocean operations. A contractor attempting underwater construction without the required skills is inviting disaster.

This chapter will discuss the general requirements and procedures that must be considered when planning and scheduling an underwater construction project.

5.2 PREPARATION BEFORE DEPLOYMENT

A successful project must be well planned before deployment of the construction team and equipment. The first step in the planning process is familiarization with the nature and details of the project and specific site conditions. Almost always a site visit is required inorder to conduct a presurvey. The presurvey should identify all important aspects of site which could affect the operations and schedule of the work. The following information should be included (9:1-4):

1. Scope of work.
2. Details of available facilities on and offshore support (work platforms, boats, concrete pumps, etc.)

3. Availability of local construction support (work platforms, boats, concrete pumps, etc.)
4. Availability of personnel support (diving facility, berthing, communications, office space, medical facilities, etc.)
5. Location of nearest recompression chamber (if not required on job site)
6. Availability of utilities (freshwater, electric power, sanitary system, high pressure air, etc.)
7. Drawings of existing facility showing original construction and any alterations or construction drawings for new facility.
8. Up-to-date charts and maps of the area.
9. Local restrictions on special operations (blasting, dredging, etc.)
10. Local tides, currents, water quality, winds, temperature, visibility, and daylight hours.

5.3 PROJECT EXECUTION PLAN

The information for this section is mainly taken from the U.S. Navy's Conventional Underwater Construction and Repair Techniques Manual, NAVFAC P-990. When the scope and existing conditions are known, an execution plan can be developed. The planning and estimating for U.S. Navy

Underwater Construction Team's (UCT'S) projects usually follows the arrow diagram as shown in Figure 39. The initial step includes (1) determining resource availability and (2) identifying activities. The determination of resource availability is required so that work methods and time to carry out the operation can be evaluated. The project activities are identified through study and inspection of the technical drawings, specifications, worksheets, and project completion reports of previous jobs, as well as discussion with those persons familiar with the project (9:1-6).

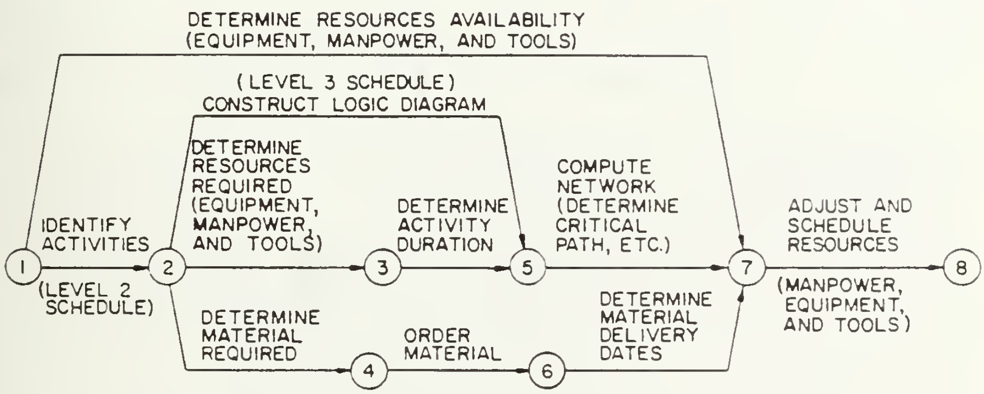


Figure 39 - Project Planning Arrow Diagram
Source: (9:1-6)

After the project activities are identified, three planning phases should start. First, the logic diagram or network of activities should be developed. Second,

resources such as manpower, equipment, and tools required for the operation and completion for each activity must be determined. Third, the materials required for the work must also be determined especially "long lead time" items.

After the resources and materials have been identified for the activities, the activity durations can be estimated. Then, using the logic diagram, the schedule network and critical path can be computed using the critical path method, bar chart, or precedence method. The NAVFAC P-990 recommends the bar chart (Gantt Chart) because it can be easily utilized and updated by field and diving personnel. A typical bar chart on an underwater construction project is shown in Figure 40.

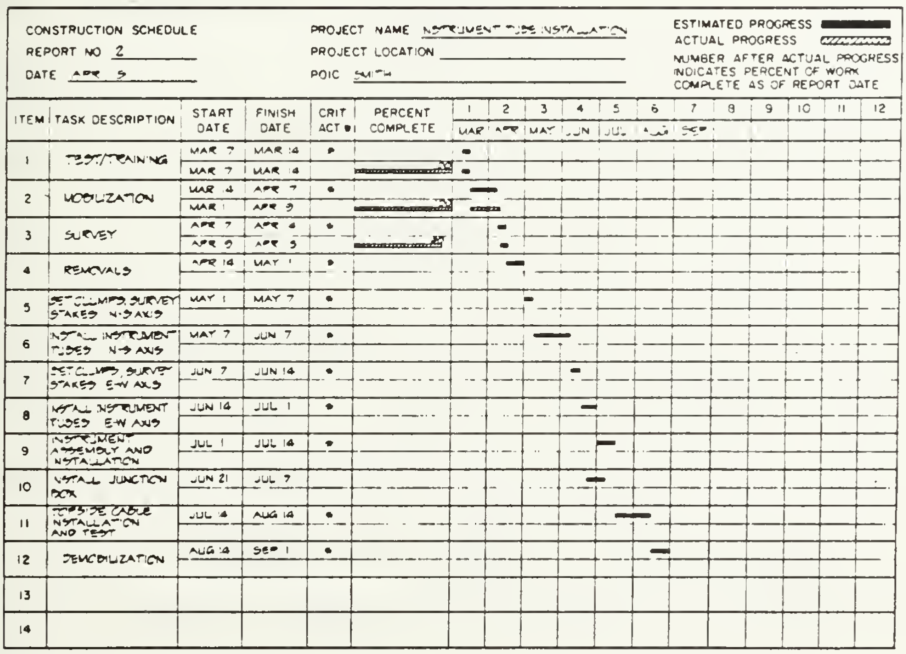


Figure 40 - Construction Gannt Chart
Source: (9:1-8)

Because diving equipment and underwater tools are specialized items, there may be many instances in which a piece of equipment that was counted on in determining the project schedule may not be available for use. Therefore, the network must then be adjusted and resources rescheduled so the project can still be completed within a reasonable amount of time.

It is especially important to plan for contingencies in underwater construction. All of the factors discussed at the beginning of this chapter must be considered in addition to the management of labor, equipment, and materials resources.

5.4 PLANNING AND ESTIMATING

Planning and estimating requires information on manpower, productivity, equipment, and materials required to carry out the various project tasks. Operations must also be well planned so that job overhead, general overhead, financing costs, and other indirect costs can be adequately estimated. Direct and indirect costs for underwater construction are considerably higher than land construction because of safety requirements, remote locations, surface support and necessary standby equipment required.

Most all of the construction references used in this report cite only labor costs for maintenance, repair, and inspection work. The lone, actual construction data for diver labor can be found in the NAVFAC P-990 which deals with construction of near shore cable and is shown in Table 8. This information is very general and is affected by the numerous variables listed in the table.

Many of the diver operated tools previously discussed have some performance data from bench tests, however, they are not representative of actual performance under true field conditions. Diver skill, depth, visibility, etc. are all variables which affect productivity. For example, drastic changes in performance can be caused by diver skill alone such as the diver operated grout gun test results between diver #4 and diver #5, previously shown in Figure 24.

The NAVFAC P-990 productivity estimates are based on good working conditions, crews with average experience and capability, and where divers are familiar with the equipment and tools needed for the job. The estimates do not account for the extra time that will be required to carry out the first few tasks as the bugs are worked out. Productivity decreases can be expected at the end of a long work day or when divers have been in the water,

Table 8 - Estimated Time Requirements for Installing Nearshore Cable

Task Description	Variables	Estimated Time Required (days)	
		Low	High
Onshore cable termination SD List 3 cable	• Type of cable	1	2
Berm removal, 500 ft long, 50 ft wide, sand	• Distance from MLW mark • Local topography • Type of soil or rock	2	4
Nearshore trenching, 500 ft long, 5 ft deep, 2 ft wide at bottom, sand	• Length, width, and depth of trench • Type of soil or rock	1	3
Installation of beach hauling equipment, 1 beach anchor, 1 deadman and sheave	• Number of deadmen and and sheaves • Local topography	3	6
Establishment of navigation and tracking system beacons	• Length of cable • Number of changes in direction	1	2
Cable stowage, on deck of barge, 18,000 ft of cable	• Length of cable • Type of cable • Type of vessel	1	2
Hauling cable ashore, including mooring barge 1,000 ft offshore	• Hauling distance • Weather/sea conditions • Type of cable	2	4
Laying inshore cable toward barge, 15,000 ft length	• Length of cable • Weather/sea conditions • Type of vessel	1	2
Beach restoration, 500 ft long, 50 ft wide, sand	• Distance from MLW mark • Local topography • Type of soil or rock	2	4
Protection & stabilization, 300 ft seaward and 100 ft shoreward of MLW mark to be protected	• Length to be protected • Type of protection • Weather/sea conditions • Method of installation		
Split-pipe		1	2
Pin anchors (in sand)		2	4
U-rods (in rock)		10	20
Rockbolts (in rock)		2	10
Jetting (in sand)		1	1

Source: (9:6-18)

particularly cold water, for a long period of time (9:1-8). In calculating the total time to complete a project, productivity must be adjusted to suit the actual conditions anticipated. Allowances must typically be made for setup and prefabrication time, start up time, relocation time, equipment downtime, downtime for weather and ship traffic, cleanup time, and packing time. Productivity rates and cost estimates therefore require sound judgement and experience. Unlike land construction, very little published data is available on underwater construction. Most underwater facilities are prefabricated on land, barged to the project site, and then sunk at a precise location. Divers and submersibles are then used to complete tie-ins such as cathodic protection, communication cables, pipelines, etc. Chapter six will discuss some cost data provided by a diving contractor for labor and equipment.

CHAPTER SIX

CONSTRUCTION COSTS

6.1 GENERAL

As mentioned in chapter 5, more cost data exists for underwater maintenance, repair, and inspection utilizing divers than for actual construction. Prefabrication is utilized whenever possible because the diver is limited in his capabilities and is also an expensive labor source. However, as more sophisticated facilities are built on the continental shelf to support the oil industry, scientific research, mining, etc. the diver will play a more active role. Underwater labor and equipment is highly specialized, therefore construction costs will remain high.

Appendix D contains cost data from a contractor that is capable of performing extensive underwater operations. The costs represent work for various diving methods and equipment such as:

1. Atmospheric diving systems
2. Remote operated vehicles(ROV)
3. Saturation diving
4. Surface diving

5. Equipment packages

6. Diving equipment rental schedule

7. Offshore workboat

8. Invoicing guidelines

The costs are mainly for labor, equipment, and consumables per day and many items of work are on a cost plus 15% basis. Materials are also on a cost plus 15% basis for the contractor. Note that the added 15% is calculated from the contractor's cost not the total project cost.

The contractor data does not specify productivity for any particular task but does mention that work will be performed with due diligence and in a safe, workmanlike manner, and according to good industry practices in the area of operations. A copy of the contractor's general provisions is included as Appendix E.

CHAPTER SEVEN

SOCIAL, POLITICAL, AND STRATEGIC IMPLICATIONS

The development of the world's oceans and utilization of its resources will have a tremendous affect on many nations of the world. Already coastal nations are claiming exclusive economic use zones (EEZ) to protect their interests in the development and use of resources on their continental shelves. Underwater construction will play a large role in establishing a nation's claim to underwater development rights.

In addition, the construction of military defenses or weapons on the continental shelves can present political difficulties and could possibly alter the balance of power between the United States and the Soviet Union (12:926-935).

Considering economic benefit, military and political significance, the development of the ocean's seabed has a definite impact on the social and political climate of the world. Within the United States, utilization of the continental resources also has a significant impact on federal and state jurisdiction. Since 1979, the National Oceanographic and Atmospheric Administration's (NOAA) Ocean Assessments Division (OAD) has been organizing and

synthesizing the best available information on important characteristics of the coastal areas and Exclusive Economic Zone (EEZ) of the United States. "Federal laws and regulations related to coastal and oceanic resources, such as the Clean Water Act, the Outer Continental Shelf Lands Act Amendments, the Coastal Zone Management Act, and the Marine Production, Research, and Sanctuaries Act, often require the explicit consideration of potential coastal and oceanic resource-use conflicts" (13:341). Possible conflicts include for example; the designation of sites for ocean waste disposal, the location of sale areas for oil and gas exploration and development, areas of biological importance, such as spawning areas for the commercial fish industry or calving areas for whales.

This type of information is generally neither well known nor well organized for decision making. However this data is currently being compiled, assessed, and communicated by the Ocean Assessment Division of the NOAA. This information is being used by the Environmental Protection Agency, the Department of Interior, the Coast

Guard, and the Army Corps of Engineers. Members of Congress and their professional staffs, who collectively set national objectives, and determine priorities through the federal budget process also utilize NOAA's information. Figure 41 is a copy from NOAA's Strategic Assessment Data Atlas for the Gulf of Mexico showing current areas being documented.

Through the advancement of diving technology and underwater tools, construction of facilities on the seabed to utilize the world's biological, mineral, and geographic marine resources will continue to expand. International, national, and social implications are just beginning to appear and will become increasingly more evident as land resources become scarce. Most attention to ocean development is made by the oil industry but the mining, scientific, and electric power industries will also focus more attention in the future.

Military use of the continental shelf especially by foreign states during peacetime will no doubt produce political ramifications. There are existing treaties which restrict and prescribe particular military uses of the oceans. These include the Limited Test Ban Treaty of 1963 (LTB), Seabed Arms Control Treaty of 1971 (SACT), and the Anti- Ballistic Missile Treaty of 1972 (ABM Treaty). In

situations where one state's military use of another state's continental shelf is not covered by these treaties, the relevant international legal principles are those contained in the provision of the 1958 Geneva Conventions on the Continental Shelf and the High Seas as well as the proposed 1982 United Nations Convention on the Law of the Sea (14:15).

Development of the Outer Continental Shelf (OCS) for commercial, economic, and military purposes will continue to be a process of government evolution both nationally and internationally (15:443).

A map from the Gulf of Mexico Strategic Assessment Data Atlas.

Figure 41 - NOAA Data Map
Source: (13:165)

CHAPTER EIGHT

FUTURE APPLICATIONS AND TECHNOLOGY AFFECTING UNDERWATER CONSTRUCTION

8.1 GENERAL

The primary driving force behind development of underwater tools and work systems will continue to be resource exploitation from the offshore oil industry as it explores deeper waters using sophisticated remote control well head completion and repair systems. Also, the need to acquire more information for military, scientific, and mining applications will also drive the development of sophisticated deep ocean work and survey systems. On site processing of resources will be the impetus for improved underwater diving and submersible tools. Offshore resources are usually brought back to shore for processing; today, tapping and processing or refining resources on site prior to transport back to shore is being attempted in many areas. For example, the Ocean Thermal Energy Conversion (OTEC) program is designed to tap the massive thermal energy storage capacity of the ocean to produce electricity on site, and the manganese nodule recovery systems currently being developed will clean and crush the nodules on the ocean floor prior to their transport to a waiting ship or ocean going processing plant (10:142).

8.2 UNDERWATER FACILITIES

Future work is anticipated to include emplacement of very large objects on the ocean floor. These objects may include foundations for mineral and energy storage and processing plants, large agriculture facilities, and large waste processing or dilution facilities.

Massive deep ocean anchors with holding capacities on the order of 2 to 20 million pounds will be needed for fixed ocean facilities. These dead weight anchors and methods for placing freshly mixed concrete in the deep ocean have been proposed by the U.S. Navy. Figure 42 and 43 demonstrate one proposed concrete placing method utilizing existing offshore oil drill ships and oil well pipe. This method could also be used to harden (or encapsulate) lost objects which contain sensitive military intelligence data such as downed aircraft, submarines, and ships. The method has the potential for significant cost savings and can also be applied to the containment of hazardous wastes. Of course, environmental aspects must be examined carefully before this practice is accepted, but the method does show promise (16:25).

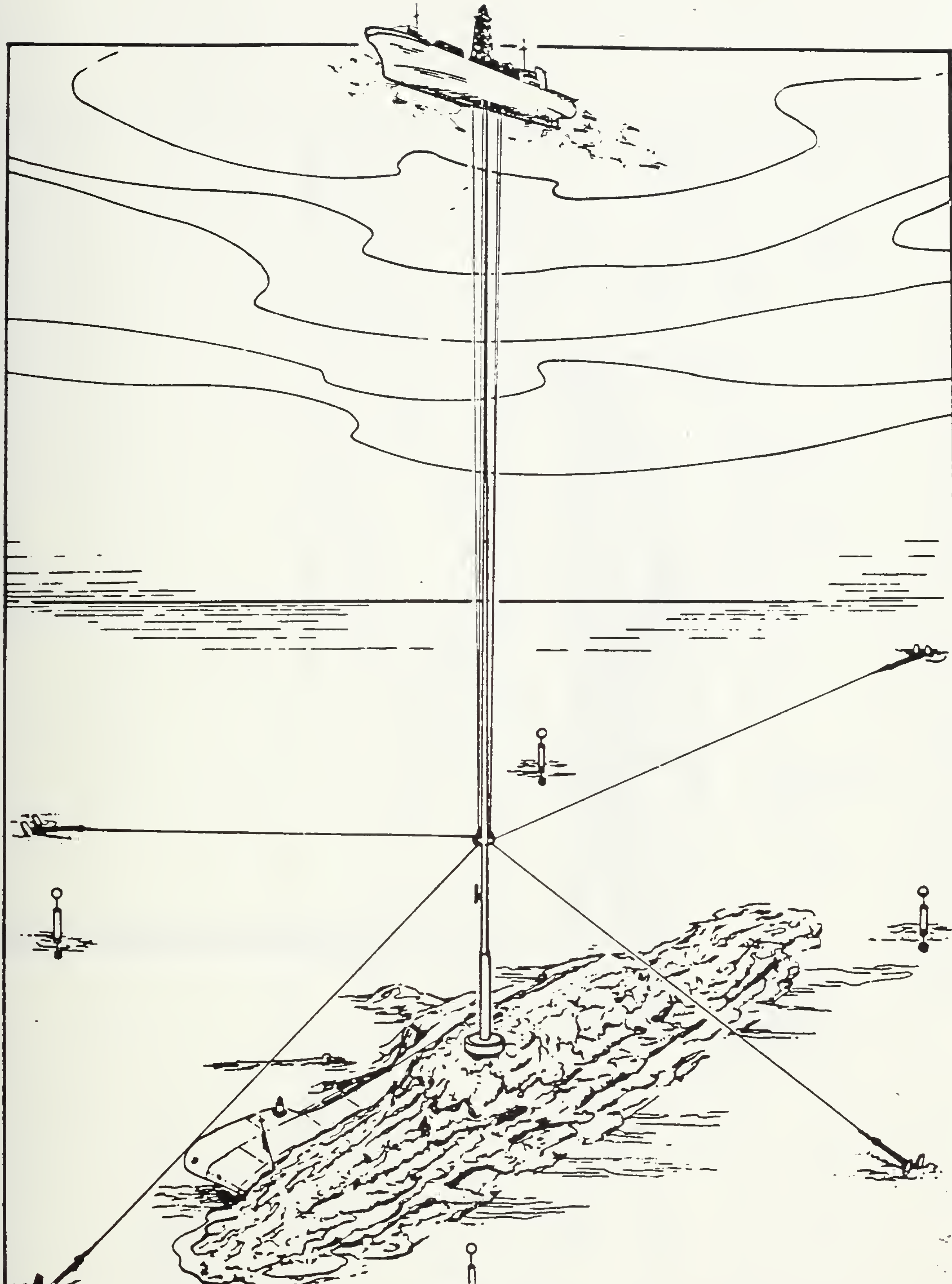


Figure 42 - Overall configuration of deep concrete placement method.
Source: (16:35)

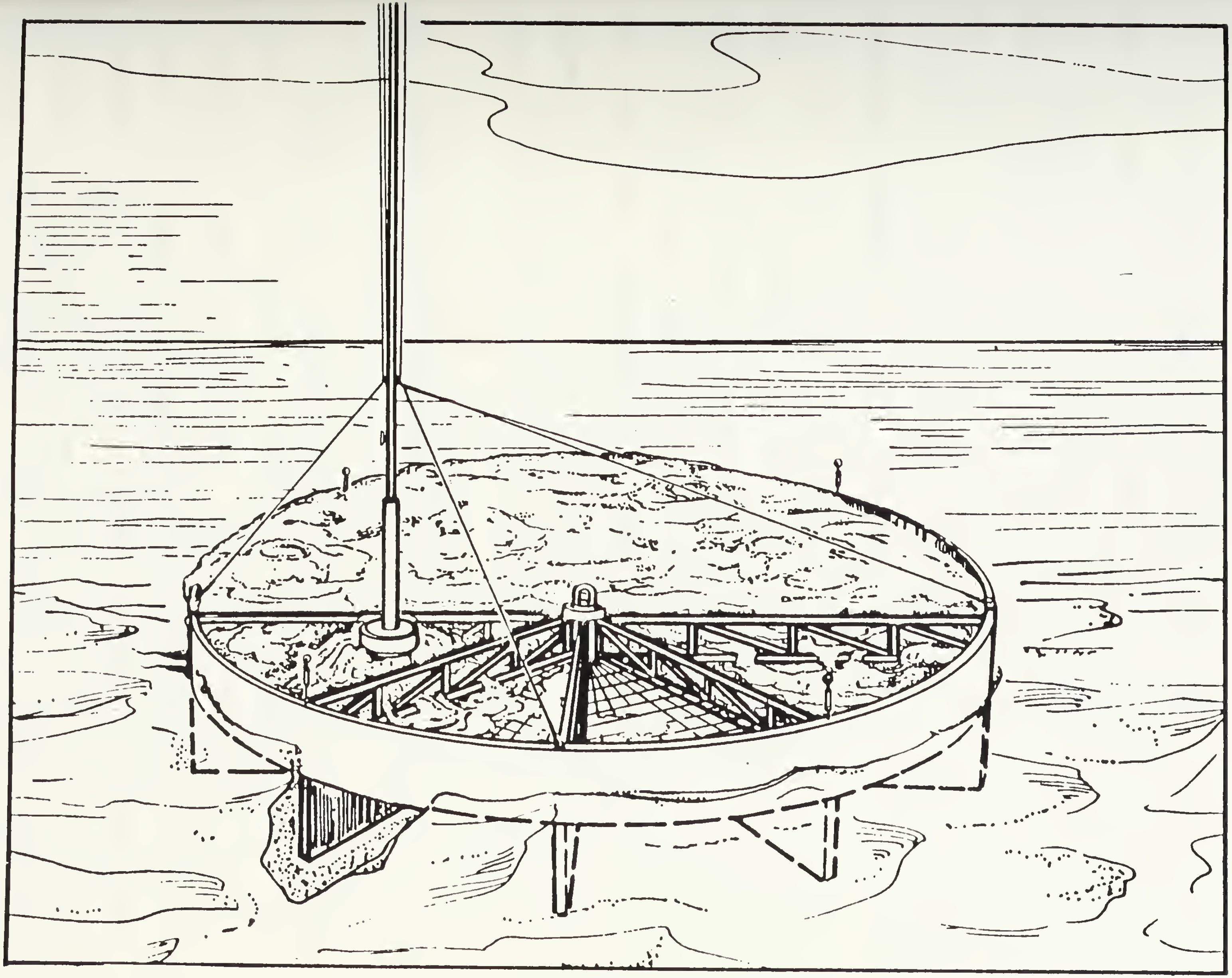


Figure 43 - Concrete placement method used to fabricate multi-million pound capacity deadweight anchor. Source: (16:34)

8.3 DIVER OPERATED TOOLS

As previously mentioned, many diver work tools are land tools modified for underwater use. Recently however new tools specifically designed for underwater use are being developed such as the seawater hydraulic tools used by the U.S. Navy. In the future, new types of tools, especially for nondestructive testing and repair of offshore platforms, will be developed, including ultrasonic thickness and flaw detection equipment (which is already in use) and ultrasonic liquid level and identification equipment. Ultrasonic techniques for removing marine growth and for creating images under limited visibility conditions are also being investigated. Underwater plasma arc, high pressure water jet, and laser cutting techniques also have great potential for future use as cutting tools (10:142).

8.4 UNDERWATER CONSTRUCTION EQUIPMENT

Manned and unmanned submersibles will play a major role in the quest to develop and construct on the continental shelf and seabed. Divers currently can't dive beyond 600 meters and therefore must use submersibles to perform work at deep ocean depths. Table 9 summarizes available information on seafloor work vehicles. These vehicles range from small, light weight equipment designed

Table 9 – Existing Bottom-Crawling Vehicles

Vehicle/Function	Water Depth (ft)	Weight in Air (lbs)	Running Gear Type	Sub-merged Ground Pressure (psi)	Obstacle Height (ft)	Seafloor Types	Builder/Owner	Year Built	Reference
Anderson Crawler Small experimental vehicle	200	~400	two tracks	<0.5	~0.5	weak mud-rock	Anderson Undersea	68	Wiendieck, 1970
Aquatech Cable Plow Cable burial	40	~4,000	skids (towed)	?	-	sands (?)	AquaTech, Inc.	?	Shuman, 1973
Atlantic Marine Dredge Sled Trench debris removal	~40	?	skids (towed)	?	-	?	Atlantic Marine & Diving	75	Sea Technology, 1977 & Peer, 1977
Atlas Copco ROC 601M Track drill	60	9,700	two tracks	?	~1	irregular rock	Atlas Copco	70	Thorstensson & Wiik, 1975
Bell Seaplow I Cable burial	1,000	27,000	four skids (towed)	4	-	silts & sands	Bell Telephone	66	Baxter & Mueser, 1971 & Anonymous, 1967
Bell Seaplow II Cable burial	2,000	31,000	four skids (towed)	4.4	-	silts & sands	Bell Telephone	67	Baxter & Mueser, 1971
Bell Seaplow III Cable burial	2,000	33,000	three skids (towed)	2.3	-	silts & sands	Bell Telephone	69	Baxter & Mueser, 1971
Bell Seaplow IV Cable burial	3,000	40,000	skids (towed)	?	-	mud-sand	Bell Telephone	75	Cobb, 1976
Bell Survey Sled Cable route survey	-	large	skids (towed)	?	-	silts & sands	Bell Telephone	65	Reidy, 1967
Cammell Laird Vehicle Diver work support	600	101,000	four wheels	2.75	2.6	mud-rock	Cammell Laird Co., Ltd.	69	Daniel, 1969, Cordy, 1977
Cal Eastern SeaCat Inspection	?	large	two tracks	?	~1	sands(?)	California Eastern Co.	~68	Wiendieck, 1970
CEL Cable Plow Cable burial	6,000	~20,000	water lubri-cated sleds	?	~0.5	mud-sand	U.S. Navy	fut.	Rockwell, 1976
CEL Equipment Chassis Test Track	600	780	single belt-type track	0.5-1.1	~0.5	clay-sand	U.S. Navy	70	Nuttall, 1970
CEL Surfzone Test Track Surfzone work support	~100	~17,000	two tracks	<5	1	silt-rock	U.S. Navy	78	
CEL Track Drill Track drill	120	~ 1,500	two tracks	?	1	rock	U. S. Navy	71	Page, 1974
Comex Cable Plow Cable burial	1,000	~44,000	two tracks	?	?	silt-sand	Comex Services	74	Cordy, 1977, Durand, 1978
CNEXO Test Module Nodule mining test vehicle	?	350	two skids	0.2	-	weak clay	CNEXO, COB	?	Cordy, 1977
Crawl Cutter Seafloor sand dredge	100	>50,000	two tracks	?	2.5	sand-coral	Ocean Science & Engineering	70	Bascom, 1970
Gopher Mark II Cable burial(?)	300	14,500	skids(?)	?	-	clay-sand	Undersea Systems	?	Anonymous, 1971
Hagenuk Cable burial(?)	?	1,100(?)	tracks	?	?	clay-sand	Hagenuk Gmblt Tyskland	72	Thorstensson & Wiik, 1975
Harmstorf Crawler Pipe burial	170	large	tracks w/skids	?	-	sand	Harmstorf, Holland	<72	Welte, 1972
Harmstorf Hydrojet Cable burial	Shallow	large	Skids w/front rollers	?	?	sand	Harmstorf, Holland	77?	Pretat, 1977
Harmstorf Sled Cable & pipe burial	600	~80,000	wheels w/skids	?	?	?	Harmstorf, Holland	64	Janes, 1976 Harmstorf & McBride, 1965

Source: (17:30)

Table 9 - Existing Bottom-Crawling Vehicles (cont.)

Vehicle/Function	Water Depth (ft)	Weight in Air (lbs)	Running Gear Type	Sub-merged Ground Pressure (psi)	Obstacle Height (ft)	Seafloor Types	Builder/Owner	Year Built	Reference
Hitachi-JADECCO Bulldozer	30	32,000	two tracks	?	?	?	Hitachi, Ltd.	69	Ocean Industry, 1969
Hitachi-JADECCO No. 1 Bulldozer	?	large	two tracks	?	?	?	Hitachi, Ltd.	?	JADECCO, 1970
Hitachi-JADECCO No. 2 Bulldozer	23	35,000	two tracks	0-3.6	?	?	Hitachi, Ltd.	69	JADECCO, 1970
Hitachi-JH-360 Bulldozer	200	70,000	two tracks	?	?	?	Hitachi, Ltd.	71	Thorstensson & Wiik, 1975
Hitachi Survey Vehicle Site survey vehicle	?	large	two tracks	?	?	?	Hitachi, Ltd.	?	Ocean Industry, 1975(c)
Jet Barge 3 (JB-3) Pipe burial	350-550	very large	skids	?	-	?	?	75	Ocean Industry, 1975(a)
Jet Barge 4 (JB-4) Pipe burial	600-1000	very large	skids	?	-	?	Santa Fe International	76	Ocean Industry, 1975(b)
Jetco Trencher Rock trencher	very shallow	large	two tracks(?)	?	?	coral-sands	Jetco, Inc.	<74	Wadsworth, 1974
Kennecott Nodule Collector Experimental nodule collection	15,000	14,000	two skids	1.0(?)	?	weak clay	Kennecott Exploration, Inc	73	Heine & Suh, 1978
Komatsu Amphibious Bulldozer Bulldozer	10	large	two tracks	9.0	?	?	Komatsu, Ltd.	69	Komatsu, 1971
Komatsu Underwater Bulldozer Bulldozer/Ripper	200	85,000	two tracks	9.5	?	?	Komatsu, Ltd.	?	Komatsu, 1971
Komatsu Underwater Bulldozer Bulldozer/Ripper	?	75,000	two tracks	8.5	?	gravelly sand	Komatsu, Ltd.	70	Ocean Industry, 1970
Komatsu Underwater Bulldozer Bulldozer/Ripper	?	93,000	two tracks	10.7	?	silty sand	Komatsu, Ltd.	?	Komatsu, 1975
Komatsu Amphibious Bulldozer Bulldozer/Ripper	50	99,000	two tracks	8.5	1.6	clay-rock	Komatsu, Ltd.	?	Komatsu, 1971
Komatsu Amphibious Bulldozer Bulldozer/Ripper	23	84,000	two tracks	8.5	?	?	Komatsu, Ltd.	71	Komatsu, 1971
Komatsu Amphibious Bulldozer Bulldozer/Ripper	10	83,000	two tracks	8.5	?	?	Komatsu, Ltd.	71	Komatsu, 1971
Komatsu Walking Machine Experimental, light work	1600	22,000	eight telescopic legs	?	large	soft soil-uneven rock	Komatsu, Ltd.	77(?)	Offshore Services, 1978
Kvaerner Pipeline Dredge Pipeline burial	1600	176,000	multiple wheels	-	-	runs on pipeline	Kvaerner Brug A/S	78	Biberg, 1978
Naucrates Search & Inspection	600	8,000	hanging slack chain	very low	>1	mud-rock	Wilson Marine Services	69	Ocean Industry, 1969(a)
NipponT&T Cable Plow Cable burial	130	?	skids(?)	?	?	?	Nippon Telephone & Telegraph	62	Baxter & Mueser, 1971
Norges Vassdrags Cable Burier Cable burial	500	large	four wheels	?	?	sand & rock	Norges Vassdrags-og Elektrisitetsvesen	77(?)	Ocean Industry, 1978

Source: (17:30)

Table 9 – Existing Bottom-Crawling Vehicles (cont.)

Vehicle/Function	Water Depth (ft)	Weight in Air (lbs)	Running Gear Type	Sub-merged Ground Pressure (psi)	Obstacle Height (ft)	Seafloor Types	Builder/Owner	Year Built	Reference
Oceanic Mole Pipe burial	200	large	?	?	?	clay(?)	Oceanics, Inc.	?	Mellor, 1977
Oceanic Seamole Pipe burial	600	large	?	?	?	clay(?)	Oceanics, Inc.	?	Mellor, 1977
PMTC Trencher Cable burial in rock	~80	~28,000	two tracks	3.9	0.5	sand-coral	U.S. Navy	75	Brackett, et al, 1976
Ponga Cutter Head Dredge Pipe burial	200	very large	sled	?	?	clays	Saipem, Italy	?	Mellor, 1977
RJBA Plow Pipeline burial	500	100,000	two large wheels	?	3.3	clay	R.J. Brown & Associates	77(?	Ocean Industry, 1977 Engineering News-Record, 1977
RUM I & II Support of research	6,000	23,000	two tracks	0-4.4	~1.5	mud-rock	Scripps Institution		Congram, 1977 Brown, 1978
Saclay Test Unit Nodule mining	17,000	200	Archimedean screw	?	?	clay	Centre d'Etades Nuclearies	77(?	Cordy, 1977
Seabug I Pipeline inspection	600	4,500	four wheels	1.4	1.3	clay-rock	U.D.I. & P&O Lines	77	Cordy, 1977
Sieverts Cable Plow Cable burial	60	24,000	sled	?	?	sand-rock	Sieverts Kabelverk	76	Engineering News Record, 1977 Peer, 1977
Sperman Marine Trencher Cable burial	shallow	medium	?	?	?	?	Sperman Marine Construction	?	Engineering News Record, 1975
Sub Sea Oil Services B70 Pipeline burial/trencher	?	large	skids on pipe	?	?	rides on pipeline	Sub Sea Oil Services	<71	Santi, 1971
Sub Sea Oil Services PBM 20 Pipeline burial/trencher	700	large	walking clamps	?	?	rides on pipeline	Sub Sea Oil Services	<71	Ocean Industry, 1975
Sub Sea Oil Services S23 Pipeline burial/trencher	200	133,000	skids	?	?	clay-rock	Sub Sea Oil Services	69	Santi, 1971
Sub Sea Oil Services Track Drill/Track drill	?	medium	two tracks	?	?	rock	Sub Sea Oil Services	<71	Santi, 1971
Sumitomo Mark III Cable burial	450	30,000	two sleds	?	?	mud-sand	Sumitomo, Yokohama	74	Sumitomo, 1977
Sumitomo SD-73/Dredger	23	136,000	two tracks	~7.4	?	?	Sumitomo Shipbuilding	74	Janes, 1976
Sumitomo Trencher/Dredge/trencher	230	132,000	two tracks	11.0	?	?	Sumitomo Shipbuilding	73	Ocean Industry, 1974
Tango Trencher Pipeline burial	500	204,000	tracks	?	?	clay-sand	Groupement EPM	76(?)	Mellor, 1977
Technomare TM-102 Dredge & pipe burial	600	420,000	two tracks	0-4.0	1.5(?)	clay-rock	Technomare, Spa	75	Banzoli, et al, 1976
Technomare TM-402 Pipe & cable burial	400	very large	two tracks	?	?	clay-sand	Technomare, Spa	78	Ocean Industry, 1978(a)
Tramp Prototype Inspection & light work	?	~5,000	six tires	1.7-3.5(?)	large	silts-rock	Winn Technology Ltd.	76	Cordy, 1977
Vickers Seacat Cable burial	450	4,000	eight wheels	5-10	0.5-1.0	clay-sand	Vickers Oceanics	77	Vickers Oceanics, 1977

Source: (17:30)

to carry small instrument packages to large sea plows for burying cable and pipeline. Heavy dredges and bulldozers are also included. The majority of these vehicles have been custom designed and built for one or two specific jobs. Only one is known to have been used on more than four jobs (17:12). The U.S. Navy is currently studying the feasibility of using different active running gear for propelling deep ocean bottom crawling vehicles. Very weak and highly plastic cohesive soils are encountered in the deep ocean as demonstrated by Figure 44 thus requiring specialized propulsion. Two different concepts of running gears are shown in Figures 45 and 46. There are also numerous unmanned research and commercially available tethered, free-swimming vehicles which will also assist and perform underwater construction tasks.

7.5 THE AQUANAUT

Because man breathes air which is compressible, he is physically limited to the depth he can dive even when using mixtures of light inert gases and oxygen. At great depths these light gas mixtures become too dense, and do not allow the lungs to function properly. The helium-oxygen limit is believed to be 600 meters.

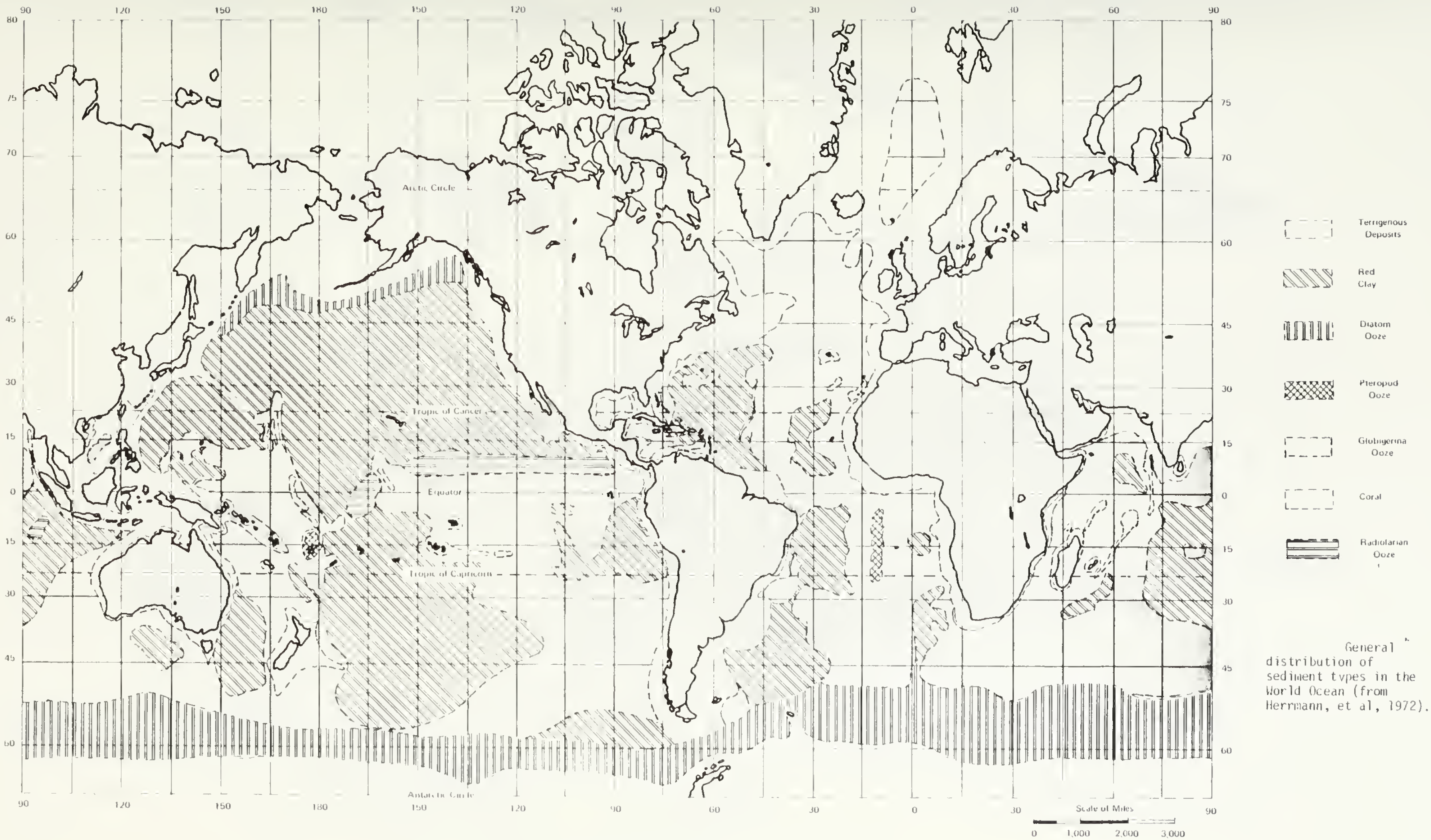


Figure 44 - General Ocean Bottom Conditions
Source: (17:42)

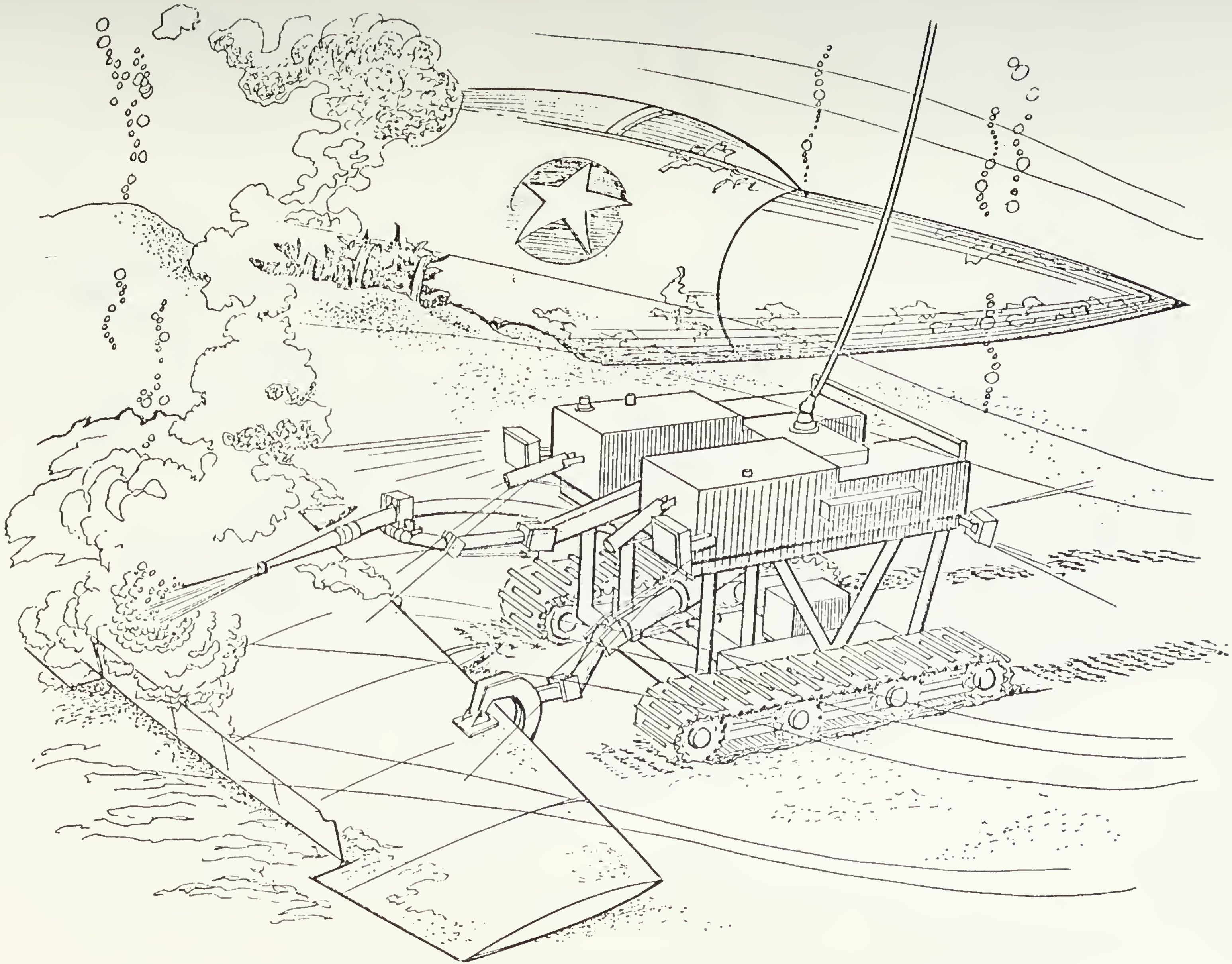


Figure 45 - Running Gear Module concept utilizing continuous belt-type track.
Source: (17:45)

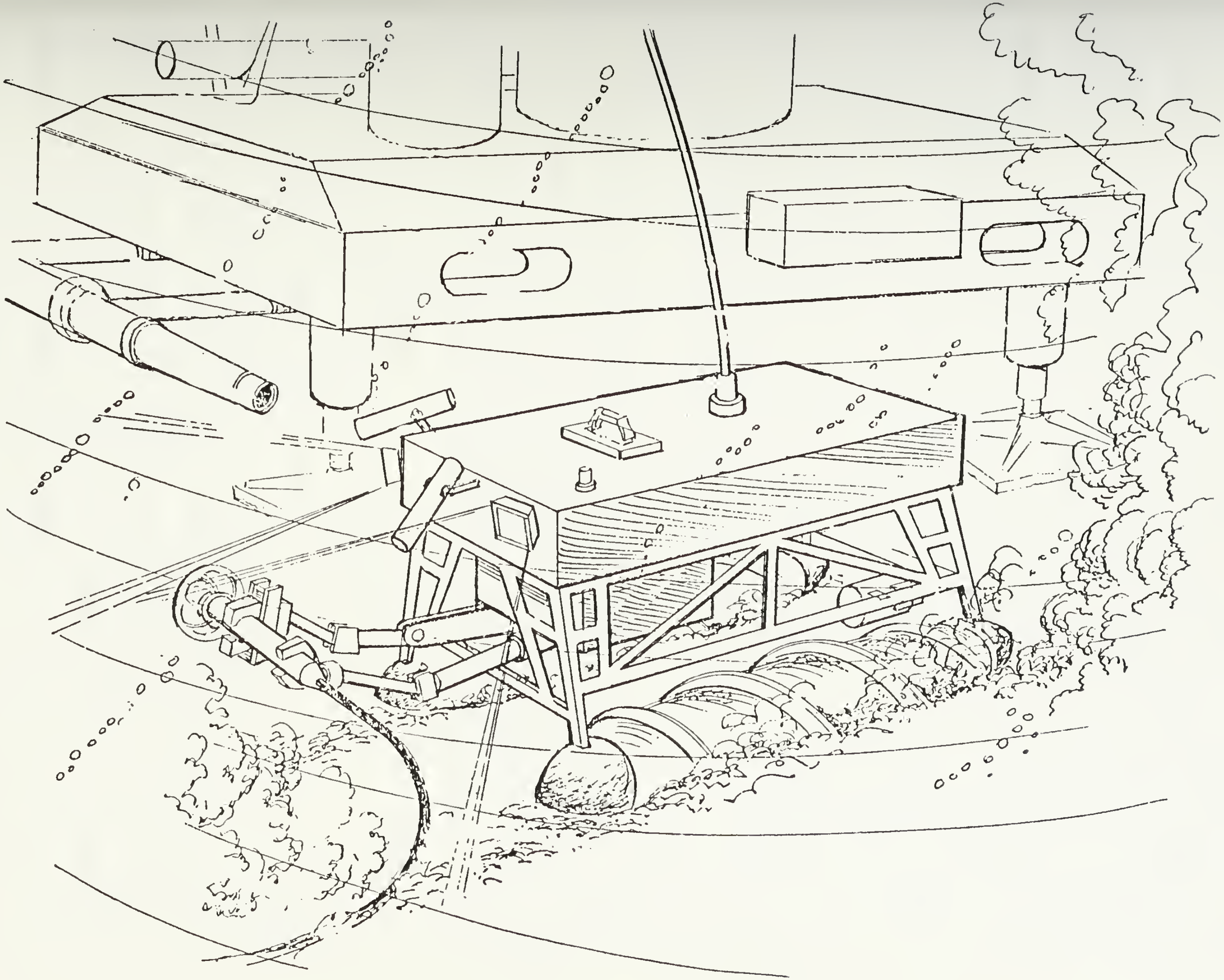


Figure 46 - Running Gear Module Concept utilizing rotor/screw.
Source: (17:46)

The future therefore will proably belong to the aquanaut, which is either a water breathing man or surgically modified man who does not breathe gases. It is possible under certain laboratory conditions to allow mammals to breathe liquids. The liquid solutions must be supersaturated with oxygen and have a salinity similar to body fluids. Figure 47 shows an experiment with a mouse breathing such a liquid. Experiments with mice and dogs have demonstrated the ability to breathe liquids and in some cases, the animals were even able to return to breathing normal atmospheric air (5:137).

There are examples of humans breathing liquids, i.e.; some people have been treated for lung ailments by irrigation with saline solutions. In fact, in one experiment, a volunteer diver breathed water in one lung while under anesthesia. It is theoretically possible, then, that under special conditions and using special fluids both lungs could function like gills. If these problems could be solved, liquid breathing divers could penetrate deep areas of the ocean and return to the surface without fear of gas bubbles forming in their bloodstream. Decompression sickness and the need for decompression chamber would no longer be needed (5:137).

Figure 47 - Experiment: Liquid Breathing Mouse
Source: (5:136)

A surgically modified man utilizing a blood exchanger could also have complete freedom of the seas. Through the use of a blood exchanger, oxygen and carbon dioxide could be directly exchanged in the blood of a diver. Artificial kidneys and mechanical hearts are already a part of medical science technology. If the current bulky equipment could be miniaturized, it would basically constitute an artificial gill composed of incompressible solids and fluids. This artificial lung would enable divers to descend to any depth and return without decompression. As shown in Figure 48, the diver's blood would be pumped through a highly oxygenated medium with the exchange of gases taking place through a semipermeable membrane. A computerized motor activator would respond to sensors which detected the gases dissolved in the blood and then adjust the flow of oxygen and the absorption of carbon dioxide. This apparatus might be a small cartridge that could easily be replaced.

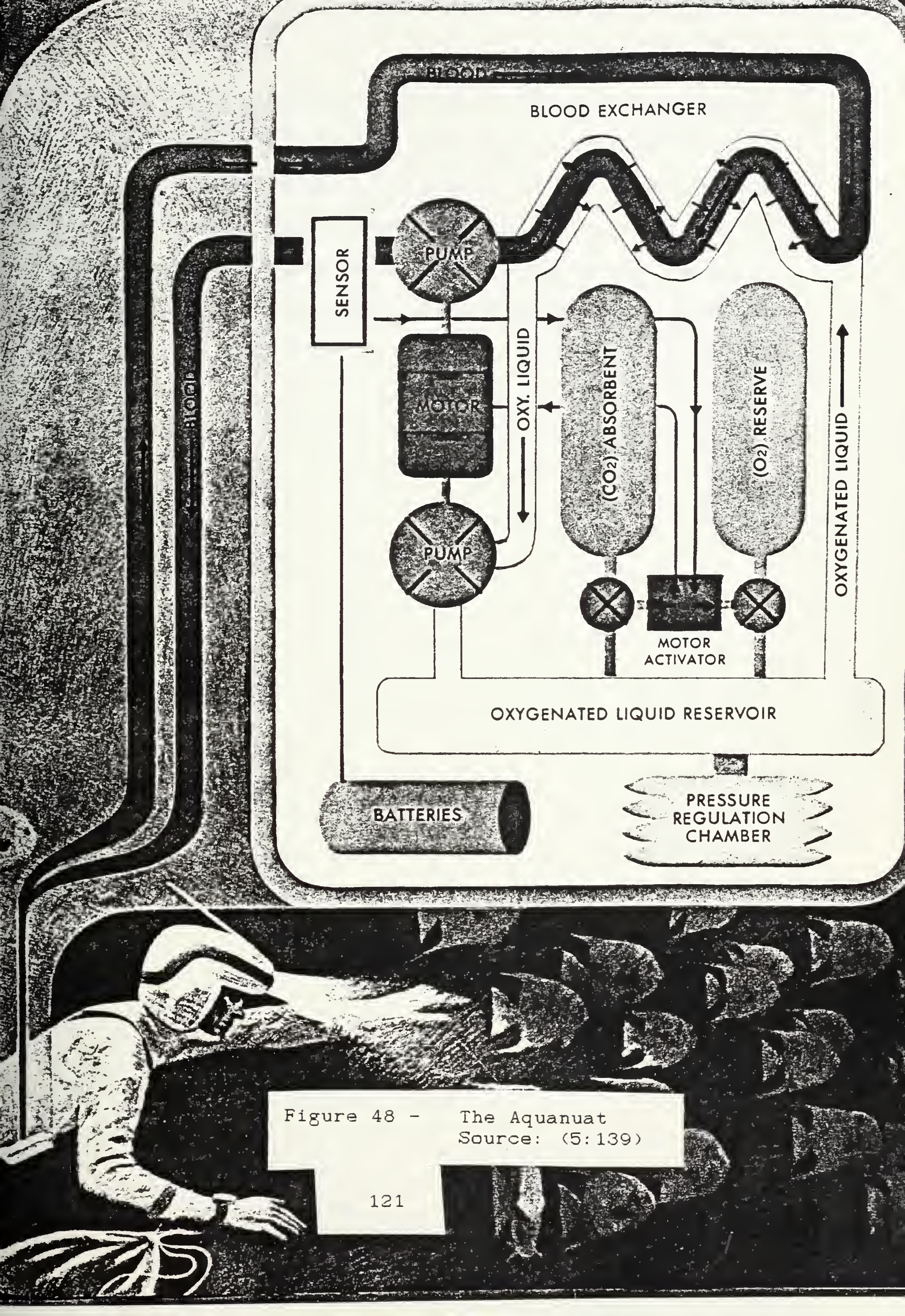


Figure 48 - The Aquanuat
Source: (5:139)

Using this cartridge the diver would have his lungs and other body air cavities filled with harmless fluid. Corrective lenses would also be added to improve his underwater vision. The underwater performance of divers so equipped would be superior in terms of depth and duration as compared to the best adapted cetaceans (whales, porpoises, etc.) (5:138).

CHAPTER NINE

CONCLUSION

The advancement of underwater tools and techniques will open new doors to man's ability to perform construction in the ocean. Since the oceans play such a large role in the earth's ability to support life man must explore it, understand it, and preserve it. To accomplish these tasks scientists and engineers must live and work in the seas which will of necessity require the construction of facilities to support scientific and exploratory operations. To reap the full potential of the oceans resources, mineral, maricultural, and scientific, on-site facilities built on the seabed will be necessary. However, there must be an equal balance in preserving the ecological existence of the ocean and its development for man's use. Therefore ocean development will require the best efforts of international cooperation and the integration of many engineering and scientific disciplines to achieve the maximum benefit for mankind.

Further development of diver tools and diver technology will be required to expand man's working ability under the sea. Without these advances man will merely play the role of an observer. The funding of research programs for developing diver tools and technology is a wise investment considering the potential wealth the sea has to offer.

The way we do or don't utilize the oceans will determine the fate of the earth and the survival of mankind. We cannot simply survive on this planet by way of default. We must take an active role in careful development of the ocean world, accurately predict the consequences of our actions, and reap as well as sow the fruits of the earth.

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APPENDIX A

SAMPLE GAS LAW DIVER CALCULATIONS

SOURCE: REFERENCE # 4, U.S. NAVY DIVING MANUAL VOL. 1

Example No. 1 —

You are stationed aboard a small salvage vessel operating out of Key West, Florida. Your ship has been given the task of locating and salvaging an LCM landing craft which had been damaged and sunk in a recent exercise.

The ship's fathometer has indicated a sharp rise on the otherwise flat bottom in 130 feet of water, and you are to make an exploratory dive to survey the contact. This first dive will be of short duration, and you will use SCUBA.

As the air tanks of the SCUBA are being charged to a capacity of 1,785 psig, the temperature in the tank has risen to 140°F. From experience in these waters, you know that the temperature at the operating depth will be about 40°F and you want to know what the gage reading will be when you first reach the bottom.

For the first step in computing the answer, fill in all known values:

P_1 = 1,785 psi (gage) + 14.7 psi (atmospheric)
= 1799.7 psia

$V_1 = V_2$ (The volume of the tank will not change, so V can be eliminated in this problem.)

Convert the temperature from degrees Fahrenheit to its absolute equivalent in degrees Rankine.

$$°R = °F + 460°$$

$$T_1 = 140°F + 460° = 600°R$$

$$T_2 = 40°F + 460° = 500°R$$

P_2 = Unknown

From the formula (with V eliminated):

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Rearranging the formula (following standard algebraic procedures) to solve for P_2:

$$P_2 = \frac{P_1 T_2}{T_1}$$

Substitute values and solve:

$$P_2 = \frac{1799.7 \text{ psia} \times 500°R}{600°R} = 1{,}499.75 \text{ psia}$$

Adjust P_2 to gage pressure:

1,499.75 psia − 14.7 psia = 1,485.05 psig

Example No. 2 —

During your initial dive, you and your buddy diver verify that the depth-finder contact is in fact the LCM. You survey the craft and determine that the damage will require a simple patch. For this job, the Diving Supervisor decides to send down a "hard-hat" diver.

You will act as tender for the dive and while the diver is getting his gear ready, you make a calculation to be certain that the air compressor you plan to use has sufficient capacity to deliver the proper volume of air to the working diver and standby diver at the operating depth and temperature.

The compressor has a suction capacity of 60 cubic feet per minute, and the temperature of the air on the deck of the ship is 80°F. The pressure at working depth is approximately 5 atmospheres absolute (ata). This is derived by dividing the depth (130 feet) by the increment of depth which has a pressure equal to one atmosphere (33 feet) and adding one atmosphere to give absolute pressure. The problem can be solved using either psi values of units of atmospheres, but not both in the same problem. Using atmospheres simplifies the arithmetic. The absolute temperatures are 540°R on the surface (80°F + 460°) and 500°R at depth, as computed in Example No. 1.

Rearrange the formula to solve for the unknown, the volume of air at depth:

$$V_2 = \frac{P_1 V_1 T_2}{P_2 T_1}$$

Substitute values and solve:

$$V_2 = \frac{1 \text{ ata} \times 60 \text{ cfm} \times 500°R}{5 \text{ ata} \times 540°R}$$

$$= 11.1 \text{ acfm at bottom conditions}$$

Based upon an actual volume (displacement) flow requirement of 4.5 cfm (CHAPTER SIX) for a deep-sea diver, the compressor capacity is sufficient to support the working and standby divers (9.0 acfm) at the 130 fsw.

APPENDIX B

DIVER PHYSIOLOGY

SOURCE: REFERENCE #4, U.S. NAVY DIVERS MANUAL VOL 1

ꞮESPIRATORY PROBLEMS IN DIVꞮNG 3.6

ꞮMany of a diver's physiological problems come about ecause he is underwater and exposed to the ressures of depth. However, some of the difficulties elated to his respiratory processes can occur at any epth or even on dry land. What these conditions have ı common is that getting oxygen to the tissue cells or etting carbon dioxide out (or both) is prevented or indered at some stage. Depth, or submergence, may ıodify these problems as the diver faces them, but the asic difficulties remain the same.

reathing is more difficult at depth because the umber of molecules packed into a given volume of as (the density) is increased in direct proportion to the bsolute pressure. For example, the air breathed at 00 feet is approximately four times as dense as the r at the surface. If open circuit gear is being used at 00 feet, each breath involves pulling four times as any molecules through the demand valve. In poorly esigned or improvised equipment, the extra effort reuired for breathing at depth will be quite noticeable nd possibly limiting. Even moving air through the spiratory passages inside the body requires about vice as much effort at 100 feet as at the surface, and e maximum breathing capacity is approximately cut half. The extra work expended in the process of eathing alone reduces the overall ability to do heavy ork at depth. The compression of gas also reduces e duration of the air supply of open circuit scuba in rect proportion to the absolute pressure.

ypoxia 3.6.1 The term hypoxia is applied to any uation in which the tissue cells fail to receive or ilize enough oxygen to maintain their life and normal nction. The many steps in the path of oxygen from e atmosphere to its metabolic use by a tissue cell ve been mentioned. Hypoxia can result from inference with any phase of the process; so, there are many possible causes and many situations in which it can develop.

One of the most obvious causes of hypoxia is lack of anything to breathe, as when a scuba diver loses his mask or mouthpiece and is exposed directly to the water, or when his air supply fails completely. In other situations, there may be enough "gas" to move in and out of the lungs but not enough oxygen available in the "gas." This may occur when cylinders with too low an oxygen content for the depth are placed accidently in the diver's gas supply line, when closed-circuit oxygen divers fail to purge exhaled nitrogen from their breathing bags, when mixed gas injectors on semi-closed apparatus or oxygen controllers on closed-circuit constant PO_2 apparatus fail; and when mixed-gas diving bells are not ventilated properly with air prior to entry by surface personnel. Medical conditions such as blockage or narrowing of the diver's air passages by secretions, vomitus or foreign material, lung damage resulting from near-drowning, severe decompression sickness ("chokes"), or toxic gas exposure can cause hypoxia. Loss of circulating blood volume from bleeding or inactivation of hemoglobin by carbon monoxide are additional causes. By far, not having an adequate content of oxygen in the breathing gas is the most common cause.

Hypoxia will stop the normal function of any tissue cell in the body and will eventually kill it, but the cells of brain tissue are by far the most susceptible to its effects. Unconsciousness and death can occur from brain hypoxia before the effects on other tissues become very prominent. Unconsciousness will develop almost at once in the complete absence of oxygen (anoxia). If some oxygen is present and/or hypoxia develops gradually, other symptoms of interference with brain function will appear. The "higher functions" are the first to be affected, just as they are in alcoholic intoxication. The ability to concentrate and think clearly, fine control of the muscles, and the ability to perform delicate or skill-requiring tasks are decreased at an early stage. Confusion, faulty judgement, emotional instability, real interference with muscle function, and difficulty in standing and walking will follow. The victim of hypoxia is usually unable to understand that he is in trouble or to be concerned about his condition. In fact, he may have the sensation of "feeling better and better" while drowsiness and weakness increase and consciousness is finally lost. In this respect, gradually developing hypoxia is very much like intoxication with alcohol.

It is the partial pressure of oxygen which determines whether the amount of oxygen in a breathing medium is adequate or not. For example, air contains about

21 percent oxygen and thus provides an oxygen partial pressure of about 0.21 atm (0.21×1 atm = 0.21 atm) at the surface. This is ample, but a drop to 0.14 atm (14 percent oxygen at the surface) will cause the onset of hypoxic symptoms. If the oxygen partial pressure goes as low as 0.12 atm (12 percent at surface), most individuals will become hypoxic to the point of being nearly helpless. Consciousness is usually lost at about 0.10 atm (10 percent at surface), and much below this level, permanent brain damage and death are only a matter of time. If the total pressure is low as at high altitude, 21 percent oxygen will not be adequate. In diving, a lower percentage will suffice as long as the total pressure is sufficient to maintain an adequate partial pressure of oxygen. For example, 5 percent oxygen should be enough if the diver is at 100 feet (5 percent oxygen $\times$ 4 atm = 0.20 atm partial pressure of oxygen); but ascent would rapidly render him hypoxic unless the oxygen percentage were increased.

When hypoxia develops, pulse rate and blood pressure increase as the body tries to offset the hypoxia by pumping more blood. A small increase in breathing may also occur. However, none of these reactions are sufficient to serve as warnings, and very few individuals are able to recognize the mental effects of hypoxia in time to take effective action.

A general blueness (cyanosis) of the lips, nail beds and skin may occur with hypoxia. Unfortunately, this is not likely to be noticed by the diver while at work and is often not a reliable indicator of hypoxia even for the trained observer at the surface. The same sign could be caused merely by prolonged exposure in cold water. If the hypoxia is caused by carbon monoxide poisoning, the lips, nail beds and skin may appear redder than normal.

The truth of the matter is that there is no natural warning by which a man can be sure of detecting the onset of hypoxia. It is the "sneaky" nature of hypoxia which makes it a particularly serious hazard in any situation where it can develop without other warnings. A diver who loses his air supply is in danger from hypoxia, but he knows he is in trouble and usually has time to do something about it. He is much more fortunate than the man who steps into an oxygen-depleted atmosphere or who gradually uses up the oxygen in a breathing rig which contains an excess of nitrogen.

In open circuit SCUBA and helmets, hypoxia is unlikely unless the supply gas has too low an oxygen content. In closed- and semi-closed Underwater Breathing Apparatus (UBA) a malfunction can cause hypoxia even though the proper gases are being used. These types of UBA's usually have oxygen sensors to read out oxygen partial pressure but divers must be constantly alert to the possibility of hypoxia from UBA malfunction.

If a man suffering from severe hypoxia is not rescued promptly, the interference with brain function will produce not only unconsciousness but also failure of the control centers which produce breathing. The heart usually continues beating for a time beyond this point. If the victim is given gas with an adequate oxygen supply before his breathing stops, he will usually regain consciousness shortly and recover completely. For SCUBA divers, this usually involves bringing the diver to the surface. For surface supplied and deep divers it involves shifting the UBA to emergency gas supplies, shifting the main gas supply to alternative banks, and ventilating the helmet or chamber with the new gas. If breathing has stopped but heart action continues, artificial respiration may succeed in getting enough oxygen to the brain to revive the respiratory center so that spontaneous breathing will resume in time. In such a case, there may already be serious damage to the higher centers; but even in these cases almost complete recovery of normal function may eventually occur. If heart action has ceased, cardiopulmonary resuscitation must be performed immediately and continued until the victim recovers or is pronounced dead by a medical officer.

Because of its insidious nature and potentially fatal outcome, prevention of hypoxia is essential. On mixed gas operations religious attention must be paid to gas analysis, cylinder line-ups, and predive check-out procedures. Breathing bags should be purged in accordance with operational procedures and oxygen sensors should be monitored closely throughout the dive. Recently surfaced mixed gas chambers should not be entered before ventilation with air.

Excessive Carbon Dioxide 3.6.2 In diving operations, an excess of carbon dioxide in the tissues (hypercapnia) is generally the result of a build-up of carbon dioxide in the breathing supply or in the body as a result of-

- — inadequate ventilation of open circuit or push-pull helmets.
- — excessive carbon dioxide in the helmet supply gas.
- — failure of CO_2 absorbent canisters in closed or semi-closed UBA's.
- — inadequate lung ventilation in relation to exercise level, caused by "skip-breathing", excessive apparatus breathing resistance, in-

creased oxygen partial pressure, or increased gas density.

— increase in UBA dead space such as failure of mushroom valves in SCUBA mouthpieces.

The most common cause of hypercapnia is failure to ventilate helmets adequately. On occasion, through improper breathing techniques or because of excessive breathing resistance, a diver can poison himself by inadequate ventilation of his own lungs. This can happen, for example, when a diver, trying to conserve his breathing supply, reduces his breathing rate below a safe level (so called "skip-breathing"). Inadequate lung ventilation is more common in diving than activities at the surface for two reasons. First, some divers have a lower drive to increase lung ventilation in the face of increased blood CO_2 levels. Secondly, the usually high partial pressure of oxygen encountered in diving takes away some of the uncomfortable shortness of breath that accompanies inadequate lung ventilation at the surface.

The chemical effects on the brain due to an excess of carbon dioxide differ from the effects due to a lack of oxygen, as in hypoxia. However, it can result in similar symptoms such as confusion, an inability to think clearly, drowsiness, loss of consciousness, and convulsions. Such effects become more severe as the degree of excess increases. A man who breathes a gas with as much as 10 percent carbon dioxide will generally lose consciousness after a few minutes. Breathing 15 percent CO_2 for any length of time will cause muscular spasms and rigidity.

Permanent brain damage and death are much less likely than in the case of hypoxia. If a diver loses consciousness solely because of excess carbon dioxide in his breathing medium and does not drown, he generally revives rapidly when given fresh air. He will usually be quite normal within 15 minutes, and the after effects rarely include more than symptoms like headache, nausea, or dizziness.

The increasing level of carbon dioxide in the blood stimulates the respiratory center to increase the breathing rate and volume, and the rate of heartbeat is often increased. Ordinarily, increased breathing is definite and uncomfortable enough to warn a diver before the concentration of carbon dioxide becomes very dangerous. However, variables such as work rate, depth and the composition of the breathing mixture may produce changes in breathing and blood circulation that could mask any changes caused by hypercapnia. This is especially true in closed-circuit breathing apparatus (especially 100% oxygen rebreathers) when failure or expenditure of the carbon dioxide absorbent material allows a carbon dioxide buildup in the face of an increased amount of oxygen. In cases where the oxygen partial pressure is above 0.5 atm, the shortness of breath usually associated with carbon dioxide toxicity may not be excessive and not noticed by the diver, especially if he is breathing hard because of exertion. In these cases the diver may become confused and even slightly euphoric before losing consciousness. For this reason, a diver must be particularly alert for any marked change in his breathing comfort or cycle (such as shortness of breath or panting) as a warning of hypercapnia.

Abnormally high carbon dioxide partial pressures in the body not only alter brain function and breathing but also produce several other effects. Blood pressure and heart rate (pulse) are increased. If the exposure to carbon dioxide is ended abruptly, there is occasionally a brief drop in blood pressure which is sufficient to cause fainting. Carbon dioxide excess also dilates the arteries of the brain. This may help explain the headaches often associated with carbon dioxide poisoning, but these are more likely to occur following the exposure than during it. It is believed that the great increase in blood flow through the brain which results from dilation of the arteries explains why carbon dioxide excess speeds the onset of oxygen poisoning. Excess carbon dioxide during a dive is also believed to increase the likelihood of decompression sickness, but the reasons are less clear. Unfortunately, effects like changes in pulse and blood presssure are of no value as warnings to the diver. Others, like headache, unusual sweating, fatigue, and a general feeling of discomfort, may warn a diver if they occur and are recognized; but they are not very reliable as warnings.

Asphyxia, Suffocation, Strangulation 3.6.3 The term asphyxia indicates the existence of both hypoxia and carbon dioxide excess in the body. It will result from cessation of breathing or serious interference with breathing from any cause. Breathing an atmosphere which is both low in oxygen and high in carbon dioxide will also produce it. In many situations, carbon dioxide excess or hypoxia occur separately, so the more specific terms should be used where possible. However, if hypoxia is severe or prolonged enough to stop a man's breathing, carbon dioxide excess will develop rapidly, and the condition will then be true asphyxia. The term suffocation is sometimes used to indicate cessation of breathing from any cause or the asphyxia that results.

Strangulation is the cessation of breathing due to injury or obstruction of air passages. This condition can be the result of such mishaps as a crushing injury to the windpipe, lodgement of an inhaled object like a ball

of gum or a false tooth, spasm of the larynx, marked swelling of the lining of the air passages, the tongue falling back into the throat of an unconscious man, or the inhalation of water, saliva, or vomitus. A victim of strangulation will generally struggle violently, trying to breathe in spite of the partial or total obstruction. This struggle may continue for a short while even after he has lost consciousness. When the asphyxia reaches a certain point, the attempts to breathe will cease. The possibility of strangulation must be, therefore, considered in any individual who is unconscious and not breathing. Artificial respiration will produce little or no movement of air in the presence of strangulation Therefore, clearing the airway is one of the very first steps in resuscitation.

Breathing Resistance and Dyspnea 3.6.4 The ability to perform useful work underwater depends on the diver's ability to move enough gas in and out of his lungs (lung ventilation) to provide sufficient oxygen to the muscles and to eliminate CO_2 produced metabolically. In the diving environment, there are two main factors that impede the diver's ability to ventilate his lungs adequately: increased gas density and resistance of the breathing apparatus.

Even in a dry hyperbarbic chamber without a breathing apparatus, the increased gas density may cause divers to experience shortness of breath (dyspnea). If breathing air, this dyspnea usually becomes apparent at very heavy work loads at depths below 120 fsw. If breathing helium-oxygen, dyspnea usually becomes a problem at heavy work loads in the 850-1000 fsw range. At great depths (1600-1800 fsw) dyspnea may occur even at rest.

The limitations imposed by the underwater breathing apparatus result from two main sources: flow resistance and static lung load. Flow resistance is due to dense gas having to flow through tubes, hoses and orifices. As gas density increases, a larger driving pressure must be applied in order to keep gas flowing at the same rate. The diver will have to exert higher negative pressures to inspire and higher positive pressures to expire. As ventilation increases with increasing levels of exercise, the necessary driving pressures will increase. Since the respiratory muscles can only exert so much inspiratory or expiratory effort, a point will be reached where further increases in ventilation will not occur. At this point, metabolically produced CO_2 will not be adequately eliminated and will build up in the blood causing symptoms of hypercapnia.

Static lung load is a result of the breathing gas being supplied at a different pressure than the hydrostatic pressure surrounding the lungs. For example: When swimming horizontally with a single hose regulator, the diaphragm is lower than the mouth and the regulator will supply gas at a slight positive pressure once the demand valve has opened. If the diver flips over on his back, the regulator diaphragm will be shallower than the mouth and the regulator will supply gas at a slightly negative pressure. Inhalation will be slightly harder but exhalation will be easier since the exhaust ports are above the mouth and at a slightly lower pressure.

Static lung loading is even more apparent in closed circuit underwater breathing apparatus such as the MK 15. When swimming horizontally, the breathing bags on the diver's back are shallower than the lungs and the diver feels a negative pressure at the mouth. Exhalation is easier than inhalation. If the diver flips over on his back, the breathing bags are below the lungs and the diver feels a positive pressure. Inhalation becomes easier than exhalation. At high work rates, excessively high or low static lung loads may cause dyspnea without any increase in blood CO_2 level.

The U.S. Navy makes every effort to ensure that UBA's meet adequate breathing standards so that flow resistance and static lung loading problems are minimized. However, all breathing apparatus have their limitations and divers must have sufficient experience on their UBA's to know what these are. Also, even if the UBA provides no limitation on ventilation, the diver's own pulmonary system may limit his ability to ventilate. Whether due to limitations of the equipment or limitations imposed by the diver's own respiratory system, the end result may be symptoms of hypercapnia or symptoms of dyspnea without increased levels of blood CO_2. Most divers will decrease their level of exercise when they begin to experience dyspnea, but in some cases, depending on the depth and type of UBA, the dyspnea may continue to increase for up to a minute after stopping exercise. When this occurs, the inexperienced diver may panic and begin to hyperventilate increasing the dyspnea further. The situation rapidly develops into one of severe dyspnea and uncontrollable hyperventilation. In this situation, if even a small amount of water is inhaled, spasm of the muscles in the voice box (laryngospasm) will occur, followed by asphyxia and possible drowning. The proper reaction in the face of dyspnea is to stop exercising, ventilate the UBA if appropriate, take even, controlled breaths until the dyspnea subsides (which it will), evaluate the situation, and proceed in an orderly manner. Generally, soreness of the respiratory muscles is the only prominent after-effect of a dive in which breathing resistance is high.

Carbon Monoxide Poisoning 3.6.5 The presence of carbon monoxide (CO) in a diver's air supply is a serious potential danger. Carbon monoxide is not found in any significant quantity in fresh air. When it does pollute the breathing supply (usually from engine exhaust in proximity to the compressor intake), even a concentration as low as .002 atmospheres can be fatal.

Carbon Monoxide causes its harmful effects by displacing oxygen from hemoglobin and combining with enzymes in tissue cells rendering them incapable of utilizing oxygen. When this happens, tissue hypoxia develops even though the supply of oxygen to the lungs is adequate and the arterial oxygen partial pressure remains high. Very small concentrations of CO can be very dangerous because hemoglobin takes up carbon monoxide 200 times as readily as it does oxygen and the amount needed to block cellular metabolism is small. In spite of the fact that oxygen has been displaced from it, hemoglobin combined with CO has a bright red color. As a result, a man who is hypoxic because of carbon monoxide poisoning may not show the cyanosis (blueness) often seen in other types of hypoxia.

Because hypoxia is the basic difficulty in carbon monoxide poisoning, the symptoms are almost identical to those of other types of hypoxia. The greatest danger is that unconsciousness can occur without reliable warning signs. When the concentration of carbon monoxide is high enough to cause rapid onset of poisoning, the victim may not even be aware of weakness, dizziness, or confusion before he succumbs. When development of toxicity is more gradual, symptoms like tightness across the forehead, headache and pounding at the temples, or nausea and vomiting may be noted in some cases. If these occur and are recognized as warnings, prompt action may save a man's life; but they cannot be depended upon.

A particularly treacherous factor in carbon monoxide poisoning is that conspicuous symptoms may be delayed until the diver begins to surface. While at the depth, the greater partial pressure of oxygen in the breathing supply will force more oxygen into solution in the blood plasma. Some of this additional oxygen reaches the cells and helps to offset the hypoxia. In addition, the increased partial pressure of oxygen forcibly displaces some carbon monoxide from the hemoglobin. During ascent, as the partial pressure of oxygen diminishes, the full effect of the carbon monoxide will be felt.

The first step in treating carbon monoxide poisoning is to get the victim into fresh air. If he is not breathing, artificial respiration must be started at once. In moderate cases of poisoning, breathing fresh air should eliminate most of the carbon monoxide from the blood in a few hours. If oxygen is available on site, it should be given as soon as possible. The administration of oxygen increases the amount of oxygen which reaches the tissues in spite of the inactivated hemoglobin, and it also increases the rate at which the hemoglobin and the enzymes involved in tissue oxidation are freed of carbon monoxide and returned to their active states.

For symptomatic cases involving neurological and/or mental changes, the administration of pure oxygen at 3 ATA is the treatment of choice. The additional 2 atmospheres of oxygen will increase the amount of oxygen dissolved in blood plasma further and will also greatly speed the rate at which the hemoglobin and oxidative enzymes are purged of the carbon monoxide and returned to normal. Brain damage which accompanies severe cases may be prevented.

If a victim of carbon monoxide poisoning resumes breathing and regains consciousness after a reasonably short period of treatment, the chances of complete recovery are good. The outcome is not so favorable if he remains in a coma for an extended period. This may indicate that considerable brain damage has occurred.

Breathholding and Unconsciousness 3.6.6 Most people can hold their breath between one and two minutes, but usuallly not much longer without training or special preparation. At some point during a breathholding attempt, the desire to breathe will become so intense that it can no longer be forestalled. This demand is signalled by the respiratory center responding to the increasing levels of carbon dioxide and acids in the arterial blood, and by the chemoreceptors responding to the corresponding fall in the level of oxygen and rise in arterial carbon dioxide.

The repeated practice of breathholding to achieve an increase in time probably has as positive an effect on the will power to resist the demand to breathe, as it does on actual improving any physical capacities. However, the length of time that a man can hold his breath can be dramatically extended by two methods which are frequently used by free divers. These are hyperventilation and breathing pure oxygen just before a dive.

Hyperventilation is breathing more than necessary to eliminate the carbon dioxide produced by the metabolism. By over-ventilating the lungs, the diver reduces the partial pressure of carbon dioxide in the blood below a normal level, and can therefore hold his breath longer while the carbon dioxide level is building

up to the point at which the respiratory center will force resumption of breathing. The practice of hyperventilation should be approached with caution, because it is the carbon dioxide level that provides the stimulus to breathe and causes the diver to feel air hunger, before hypoxia occurs and causes unconsciousness.

f the carbon dioxide stores are ventilated below the stimulus level, there will be little urge to breathe until ate in the breathhold. The oxygen partial pressure, however, will progressively fall as oxygen is consumed continuously. Since low levels of oxygen do not force a powerful demand to resume breathing, the level of oxygen in the blood may reach the point at which the liver will lose consciousness before he feels a demand to breathe.

'ree divers who hyperventilate and breathe pure oxyen before a dive have markedly increased times for neir dives. The breathing of oxygen puts a high conentration of the gas in the lungs which, in turn, keeps safe quantity of oxygen in the blood for a longer eriod of time than if the lungs were filled with air. The urrent world record for underwater breathholding, chieved with the aid of these techniques, is more ian 13 minutes. However, any diver should approach ie use of such methods with extreme caution and do only under competent supervision.

ne of the greatest hazards of deep breathhold diving the possible loss of consciousness during ascent. r in the lungs during descent is compressed, raising e oxygen partial pressure. The increased partial essure readily satisfies the body's oxygen demand ring descent and while on the bottom, even though a rtion is being consumed by the body. During ascent, wever, the partial pressure of the remaining oxygen reduced rapidly as the hydrostatic pressure on the dy lessens. If the partial pressure drops below 25 mHg, unconsciousness may result with its attendant ngers. This danger is further heightened when perventilation has eliminated normal body warning ns. Such unconsciousness may occur even with ior oxygen breathing if the underwater stay is ngthy.

'perventilation with air before a skin dive is almost indard procedure and is reasonably safe if it is not rried too far. Hyperventilation with air should not be ntinued beyond 3 to 4 breaths and the diver should irt to surface as soon as he notices a definite urge to sume breathing. Underwater breath-holding conits and attempts to set records for underwater swimng distance and the like should be avoided. Disturnces of heart action have resulted from feats of this kind, and over-enthusiastic breathholding has resulted in a number of fatal accidents.

Hyperventilation 3.6.7 Hyperventilation is the term applied to breathing more than is necessary to keep the body's carbon dioxide tensions at proper level. It has already been discussed in the preceeding paragraphs in connection with breathholding. If carried to an extreme, hyperventilation can be as undesirable and dangerous as conditions involving interference with breathing. Unintentional hyperventilation is most often triggered by nervous tension and can be experienced by otherwise normal individuals in stress situations. It is also brought on by hypoxia and is a common and serious problem with aviators and mountain climbers at high altitudes. Divers using self-contained equipment for the first few times are likely to hyperventilate to some extent largely because of anxiety. Hyperventilation has little effect on the body's oxygen levels, but it can reduce carbon dioxide partial pressures to the point of producing serious symptoms.

Symptoms of abnormally low carbon dioxide tension (hypocapnia) can be produced by voluntary hyperventilation—taking a number of deep breaths over a short period of time. Under these circumstances, one rarely develops more than lightheadedness and tingling sensations. When a man hyperventilates over a long period, however, additional symptoms such as weakness, headaches, numbness, faintness, and blurring of vision may appear. Often hyperventilation is initiated by a nervous sensation of suffocation which continues in spite of adequate ventilation. The anxiety caused by the symptoms may lead to a further increase in breathing, and a vicious cycle can thus develop. Severe hypocapnia with muscular spasms, loss of consciousness, and shock may be the end result. Clear-cut cases this severe are extremely rare in diving, but the possibility deserves attention. Milder instances are probably common.

In more severe cases of hyperventilation, having the individual rebreathe his expired air from a rubber bag or paper sack for a short while (less than a minute at a time) may relieve the symptoms and cause him to stop hyperventilating.

Hypoglycemia 3.6.8 A condition which is not due to respiratory difficulties but which can sometimes be confused with them is hypoglycemia, an abnormally low blood sugar (glucose) level. Sugar, derived from food, is the body's main fuel. It is carried to the tissues by the blood; and if the blood level falls for some reason, the functions of the tissues will be disturbed.

The brain is especially sensitive to lack of glucose. The highly variable symptoms can sometimes closely resemble those of other conditions in which brain function is affected, including carbon dioxide intoxication, hypoxia, carbon monoxide poisoning, and even oxygen poisoning and air embolism. Some of the more common symptoms are unusual hunger, excessive sweating, numbness, chilliness, headache, trembling, dizziness, confusion, lack of coordination, anxiety, and fainting. In severe cases, loss of consciousness and convulsions may occur. There are several possible causes of hypoglycemia. Simply missing a meal will tend to reduce the blood sugar level, but the body normally can draw on its stored supplies to keep the level close to normal for a long time. A few individuals who are otherwise in good health will develop some degree of hypoglycemia if they do not eat at fairly frequent intervals. Severe exercise on an empty stomach will occasionally bring on the symptoms even in a man who ordinarily has no abnormality in this respect. The body secretes insulin which promotes the normal use and storage of glucose. People with diabetes do not secrete enough insulin and for this reason have an excess of glucose in their blood. They must take insulin by injection to avoid the symptoms of the disease and to keep their blood sugar level where it belongs. If they happen to take too much, or if some factor like unexpectedly hard work reduces the amount needed, serious hypoglycemia can develop rapidly. This is one of the main reason why diabetecs are considered "bad risks" in diving.

If hypoglycemia is present, giving sugar by mouth (or glucose intravenously, if the victim is unconscious) will relieve the symptoms promptly and prove the diagnosis. If a diving operation is going to require going without food for an unusually long period, eating protein foods like meat before-hand will provide a longer and steadier supply of glucose than will loading up on starches and sweets. The latter procedure can actually cause trouble in some individuals by causing the body to secrete an excess of insulin. A diver who often experiences definite weakness (or other symptoms mentioned) when he misses meals should have a medical workup to determine whether hypoglycemia is the cause and, if so, why he is particularly susceptible to it.

BODY TEMPERATURE AND HEAT LOSS 3.7

Next to decompression, thermal problems arising from exposure to cold water pose the major consideration in operational dive planning and the major consideration in equipment selection. The working diver commonly experiences continuous heat loss during immersion and often expects to be uncomfortably chilled at the end of a dive. Bottom times may be determined more by the diver's cold tolerance than by decompression considerations. Rewarming before a repetitive dive can be as important as the calculation of residual nitrogen in repetitive diving.

The human body functions effectively within a relatively narrow range of internal temperature. The average, or "normal" level of 98.6°F (37°C) is maintained by natural mechanisms of the body, aided by artificial measures such as the use of protective clothing or air conditioning when external conditions lend toward extremes of cold or heat.

The metabolic processes of the body constantly generate enough heat each hour to warm 2 liters of ice cold water to body temperature, and during heavy work more than 10 times as much heat may be generated. If heat were allowed to build up inside the body, it would soon reach a high enough level to actually damage the cells (approximately 105°F, 41°C). In order to maintain internal temperatures at the proper level, the body must lose heat equal to the amount it produces.

Heat transfer is accomplished in several ways. The blood, circulating through the body, picks up excess heat and carries it to the lungs where some of it is lost with the exhaled breath. Heat is also transferred to the surface of the skin, where much of it is dissipated through a combination of conduction, convection, and radiation. Moisture released by the sweat glands cools the surface of the body as it evaporates, facilitating the transfer of heat from the blood to the surrounding air. If the body is working hard, and therefore generating greater than normal quantities of heat, the blood vessels nearest the skin will dilate to permit more of the heated blood to reach the body surfaces, and the sweat glands will increase their activity.

If the surrounding air is hot, the rate of heat transfer will be slower than in cool air, and if the humidity is high, evaporation of moisture from the skin will be greatly inhibited. For these reasons, a man cannot do as much work on hot, humid days as on cold, dry days.

The maintenance of proper body temperature is particularly difficult for a diver working underwater. In warm tropical waters (above 86°F, 30°C), the cooling systems of the body will be ineffective and a working diver may find himself approaching a state of heat exhaustion. High temperature waters are the exception

ı diving, however, and the principle temperature con-ol problems encountered by divers involve keeping ıe body warm. The high thermal conductivity of ·ater, coupled with the normally cool-to-cold waters in ʼhich they operate, can result in rapid and excessive eat loss.

ntry into cold water is itself a shock that can distract ıe diver. The same is true whenever he experiences a ıdden drop in skin temperature, such as when move-ıent brings cold water into a wet suit or when a dry ıit leaks. If a man with no thermal protection at all ıddenly plunged into very cold water, the effects are ımediate and rapidly disabling. There is a gasping ·sponse and a period of increased respiratory rate ıd an increased tidal volume. The breathing is rapid, ith breathing control involuntary, so the swimmer ınnot coordinate his breathing and swimming ovements. The lack of breathing control makes sur-val in rough cold water very unlikely. In freezing ater, collapse from exhaustion occurs in 1-5 minutes, ·pending on the amount of body fat the swimmer has.

water temperature of approximately 91°F (33°C) is quired to keep a man at absolute rest at a stable mperature. In water temperatures below 72°F 3°C), the unprotected diver will be affected by ex-·ssive heat loss and become chilled within a short ·riod of time. As the body temperature is reduced, he ll first feel uncomfortable and then, as his body tries increase heat production in the muscles, he will gin to shiver. If cooling continues, his ability to per-·m useful work may become seriously impaired. The nds lose dexterity and the sense of touch is dulled. , shivering intensifies, it brings on a general lack of ordination and it may even be difficult for a SCUBA ·er to keep his mouthpiece in place. It becomes in-·easingly difficult to concentrate, and the ability to nk clearly is soon lost.

, extremely low temperatures, or with prolonged im-·rsion, body heat loss will reach a point at which ·ath will occur. In water at 42°F (6°C), an unclothed ın of average build will become helpless within 30 ·nutes and will probably die within an hour. Ap-·propriate dress can greatly reduce the effects of heat ·s, and a diver with proper dress can work in very ·d water for reasonable periods of time.

·e ability of the body to tolerate cold environments is ·e to natural insulation and the body's built-in means heat regulation. Usually, the body temperature is ·ught of as being 98.6° F (37° C), but in fact the ·nperature is not uniform throughout the body. It is ·re accurate to consider the body with an inner core ·ere a constant or uniform temperature prevails, and a superficial region, through which a temperature gradient exists from the core to the body surface. Over the trunk of the body, the thickness of the superficial layer may be approximately 1 inch (2.5 cm). The extremities become a superficial insulating layer when their blood flow is reduced to protect the core.

Once in the water, man becomes largely dependent on internal mechanisms to limit the loss of body heat if no supplemental heating is provided. Heat loss through the superficial layer is lessened by the reduction of blood flow in the skin. The automatic cold-induced vasoconstriction (narrowing of the blood vessels) lowers the heat conductance of the superficial layer and acts to maintain the heat of the body core. Unfortunately, vasoconstrictive regulation of heat loss has only a narrow range of protection. When the extremities are initially put into very cold water, vasoconstriction occurs and the blood flow is reduced to preserve body heat. After some time, however, the blood flow increases and fluctuates up and down for as long as the extremities are in cold water. As circulation and heat loss increase, the body temperature falls and may continue falling even though heat production is increased by shivering. This effect, called cold vasodilation, occurs only in water colder than 50°F (10°C), and appears to be caused primarily by direct cold paralysis of the blood vessels in the skin.

Much of the heat loss in the trunk area is transferred over the short distance from the deep organs to the body surface by simple physical conduction, which is not under any physiological control. Most of the heat lost from the body in moderately cold water, therefore, is from the trunk and not from the limbs. Heavy-set men lose much less heat from the trunk than thin men because of the insulating properties of thick subcutaneous fat.

Normally, exercise increases heat production and increases body temperature in dry conditions. Paradoxically, exercise in cold water may make the body temperature fall more rapidly. Any movement which stirs the water in contact with the skin may create turbulent eddies that carry off heat. Heat loss is not caused by just water movement, but also by the increased blood flow into the limbs during exercise. Continual movement makes the limbs more closely resemble the internal body core rather than the insulating superficial layer. These two conflicting effects result in the core temperature being maintained or increased in warm water and decreased in cold water.

A diver must understand that increased heat production requires an equivalent increase in oxygen consumption. Further, the minute ventilation of the lungs

must increase by the same magnitude. If a diver is breathing 12 liters of air per minute at rest in the water and he becomes chilled, his heat production may increase three times to compensate for chilling. His respiratory ventilation will then increase to 36 liters per minute. In this example, the diver would have the same air consumption at rest keeping warm as he would have if he were performing moderate work in warm water.

All of these factors weigh against the diver, with the rate of heat loss depending on the severity of his exposure. Even his natural insulation and the body's own protective function give way to especially cold water. The diver's thinking ability becomes impaired, and the effect of this impairment on the use of his hands and other motor function may prevent him from choosing and executing the best procedures to complete his task. In some cases, his survival may be at stake.

The signs and symptoms of dropping body core temperature from the first noticeable effects to death are listed in Table 3-2. It must be remembered, though, that there are sudden, acute effects from immersion in cold water that have their onset immediately and independently of dropping core temperature.

BAROTRAUMA AND MECHANICAL EFFECTS OF PRESSURE 3.8

The tissues of the body can withstand tremendous pressure: men have made actual ocean dives to 1148 fsw (350 meters) and, in experimental situations, have been exposed to pressure equivalent to a dive of 2250 fsw (686 meters). Animals such as mice, goats and monkeys, have withstood pressures equivalent to dives as great as 5577 fsw (1700 meters).

As great as these pressures have been, it is somewhat ironic that the cause of the greatest number of medical complaints is often seen in the shallowest part of a dive. The cause is barotrauma, which is damage done to tissues when there is a change in ambient pressure.

There are four essential ingredients that must be present for barotrauma to occur. First, there must be a gas filled space. Most of the body is fluid and is not compressible. However, any gas filled space naturally present within the body, such as the sinuses, or next to the body, such as a face mask, can damage body tissues when the gas volume changes according to Boyle's Law. Second, the space must have rigid walls. If the walls were elastic like a balloon, there would be no damage done by the gas compression or expansion. Furthermore, the space must be enclosed. If any substance were allowed to freely enter or leave the

TABLE 3-2 SIGNS AND SYMPTOMS OF DROPPING CORE TEMPERATURE

Core Temperature °F	Core Temperature °C	Symptoms
98.6	37	Cold sensations Skin vasoconstriction Increased muscle tension Increased oxygen consumption
97	36	Sporadic shivering suppressed by voluntary movements Gross shivering in bouts Further increases in oxygen consumption Uncontrollable shivering
95	35	Voluntary tolerance limit in laboratory experiments Mental confusion Impairment of rational thought Drowning possible Decreased will to struggle
93	34	Loss of memory Speech impaired Sensory function impaired Motor performance impaired
91	33	Hallucinations, delusions, clouding of consciousness In shipwrecks and survival experience, 50% do not survive Shivering impaired
90	32	Heart rhythm irregularities Motor performance grossly impaired
88	31	Shivering stopped
86	30	Loss of consciousness No response to pain
80	27	Death

pace as the gas volume changes, then no damage /ould occur. And finally, there must be a change in mbient pressure.

.ll four of these factors must be present for arotrauma to occur. It can happen on descent or as-ent. Barotrauma of descent is usually called squeeze. arotrauma of ascent is called reverse squeeze. It is nportant to note that barotrauma can be minimized if ıe diver is healthy, has properly functioning equip-ıent, and uses correct procedures.

ıe predominant symptom of barotrauma is pain. On əscent, the pain is accompanied by bleeding in əvere cases as blood vessels engorge or rupture to əlieve the relative vacuum within the space as the gas ɔlume is compressed. On ascent, the pain may be ac-ɔmpanied by decreased blood flow to surrounding ructures as the gas within the space expands and im-əedes circulation. Other unusual symptoms such as ərtigo, numbness, or facial paralysis may be pro-ıced depending on the specific anatomy. Pulmonary /erinflation syndrome is a potentially serious form of ırotrauma and will be discussed in detail in Section 9. In all diving situations, arterial gas embolism and əcompression sickness must be ruled out before the agnosis of squeeze can be accepted.

the remainder of this section, specific types of ırotrauma and their related conditions will be re-əwed.

iddle Ear Squeeze **3.8.1** The anatomy of the ear diagrammatically shown in Figure 3-12. The ear um completely seals off the outer ear canal from the iddle ear space. When the diver descends, water essure on the external surface of the drum in-eases. To counterbalance this pressure, the air essure must also reach the inner surface of the ear um. This is accomplished by the passage of air rough the narrow Eustachian tube which leads from e nasal passages to the middle ear space.

ıould the Eustachian tube be blocked by mucus or an 'ergrowth of tissue, this equalization of pressure on ıth sides of the ear drum cannot take place. When əscent begins, the eardrum will bow inward and tially equalize the pressure by compression of mid-ə ear gas. Soon, however, the ear drum stretches out d reaches its limits of inward distensibility. At this ıint, middle ear pressure falls below the external ıter pressure creating a relative vacuum in the mid-ə ear space. This negative pressure causes the ɔod vessels of the ear drum and of the lining of the ddle ear initially to expand, then to leak, and finally rst. If descent is continued, either the eardrum will

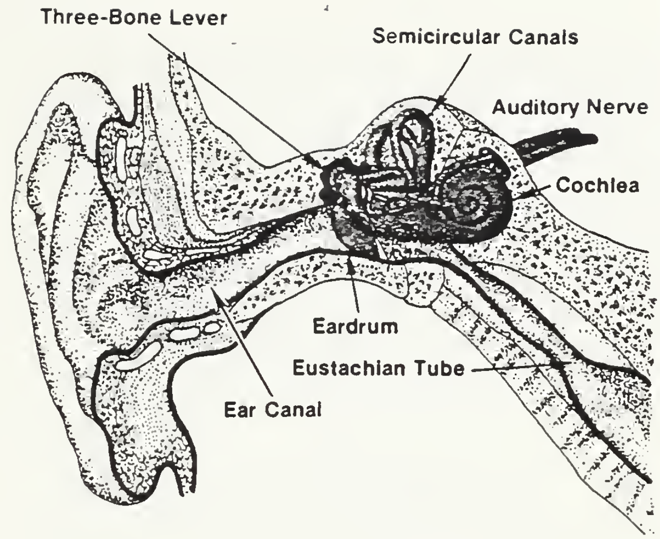


Figure 3-12. Cross-sectional view of the ear. The ear drum separates the external ear canal from the middle ear space. Sound waves vibrate the ear drum. These vibrations are transmitted to a part of the inner ear called the cochlea via the three bone lever arm (the ossicles; malleus, incus and stapes). Excitation of cochlear nerve fibers produces hearing. The three semi-circular canals, sometimes called the labyrinth, are another part of the inner ear and are responsible for balance. The Eustachian tube allows air to pass between the middle ear space and nasal passages, thus permitting equalization of pressure differences across the ear drum.

rupture allowing the inward rush of water to equalize the negative pressure, or rupture of blood vessels will cause sufficient bleeding into the middle ear to equalize the pressure. The latter is the usual course of events.

The hallmark of middle ear squeeze is sharp pain caused by stretching of the ear drum. The pain produced before rupture of the drum often becomes so intense as to prevent further descent of the diver. Returning to normal pressure brings about immediate relief.

If descent is continued in spite of the pain, the ear drum may indeed rupture. Unless the diver is in a hard hat diving dress, the middle ear cavity will be exposed to water when the drum ruptures. This presents the possibility of ear infection and will prevent the diver from diving until the damage is healed. At the time of the rupture, the diver may experience the sudden onset of a brief but violent episode of vertigo (a sensation of spinning). The diver can become completely disoriented, will probably become nauseated and may vomit. The vertigo in this case is produced by cold water stimulating the balance mechanism of the inner ear. This is called Caloric Vertigo. Caloric Vertigo may also occur just from having cold water enter one ear and not the other. Even with an intact eardrum this can produce vertigo. This type of caloric vertigo results

when one ear canal is blocked (e.g. by ear plugs, tight fitting wet suit hood, severe external otitis or a wax impaction) when swimming or diving in cold water. Fortunately, these symptoms will quickly pass when the water reaching the middle ear is warmed by the body.

The best means of handling middle ear squeeze is to avoid it. Remember that barotrauma can be virtually eliminated if certain precautions are taken. When descending, stay ahead of the pressure by clearing the ears. If too large a pressure difference exists between the middle ear pressure and the external pressure, the Eustachian tube will collapse, much like a straw will while trying to focibly suck a thick shake through it. To avoid collapse and occlusion of the Eustachian tube, it is necessary to make frequent adjustments of middle ear pressure by adding gas through the Eustachian tubes from the back of the nose, a process called clearing the ears. For a few divers, the Eustachian tube is open all the time so no conscious effort is necessary to clear their ears. For the majority, however, the opening of the Eustachian tube is normally closed and some action must be taken to clear the ears. Many divers can do this by yawning, swallowing, or moving the jaw around. Some divers must gently force gas up the Eustachian tube by closing thier mouth, pinching their nose, and exhaling (Valsalva maneuver). Once too large a relative vacuum exists in the middle ear, the Eustachian tube will collapse and no amount of forcible clearing will open it. If a squeeze is noted during descent, then the diver should ascend

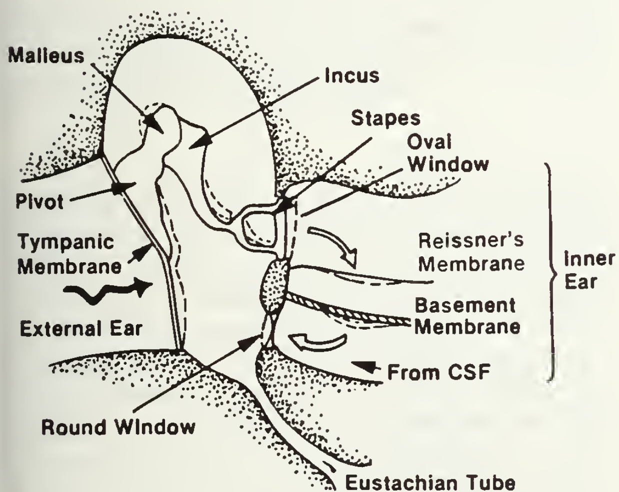


Figure 3-13. Middle and inner ear structures. Sound-induced vibrations of the ear drum are transmitted via the malleus, incus, and stapes to the oval window of the inner ear. Deflections of the inner ear membranes by the fluid waves thus created produce hearing. Since the inner ear is completely fluid filled, any inward deflection of the oval window must be matched by an outward deflection of the round window.

a few feet and gently perform a Valsalva maneuver. NEVER DO A FORCEFUL VALSALVA DURING DESCENT, THIS COULD RESULT IN ALTERNOBARIC VERTIGO OR A ROUND OR OVAL WINDOW RUPTURE (see paragraph 3.8.10). If clearing cannot be accomplished in this way, the dive should be aborted.

Upon surfacing after a middle ear squeeze, the diver may complain of pain, fullness in the ear, hearing loss or even mild vertigo. Occassionally, there may be blood in the nostril. Treatment consists of decongestants and cessation of diving until damage is healed.

Diving with a partially blocked Eustachian tube increases the likelihood of middle ear squeeze. Divers who cannot clear their ears on the surface should not dive. Divers who have trouble clearing should be examined by a Medical Officer or Diving Medical Technician before diving.

Sinus Squeeze **3.8.2** The nasal accessory sinuses are shown diagrammatically in Figure 3-14. All sinuses are located within hollow spaces of the skull bones and are lined with mucus membrane continuous with that of the nasal cavity. The sinuses are small air pockets which connect with the nasal cavity through narrow passages. If pressure is applied to the body, and passages to any of these sinuses are obstructed by mucus or tissue growths, pain will soon be experienced in the affected area. The situation will be very much like that described in the middle ear. When the air pressure in these sinuses is less than the pressure applied to the tissues surrounding these incompressible spaces, the same relative effect is produced as if a vacuum were created within the sinuses. Swelling of the lining membranes and, if severe enough, hemorrhage into the sinus spaces, will take place. This process represents an effort on the part of nature to balance the relative negative air pressure with swollen tissue, fluid, and blood. A "squeeze" of the sinuses actually takes place. The pain produced may be severe enough to prevent further descent of the diver. Unless damage has already occurred, a return to normal pressures will bring about immediate relief as in the case of pain from the middle ear. If such difficulty has been encountered during a dive, the diver may often notice a small amount of bloody nasal discharge on reaching the surface.

Sinus squeeze can often be prevented by not diving if any signs of nasal congestion or a head cold are apparent. The effects of squeeze can be limited during a dive by halting the descent and returning toward the surface a few feet. This will help restore the pressure

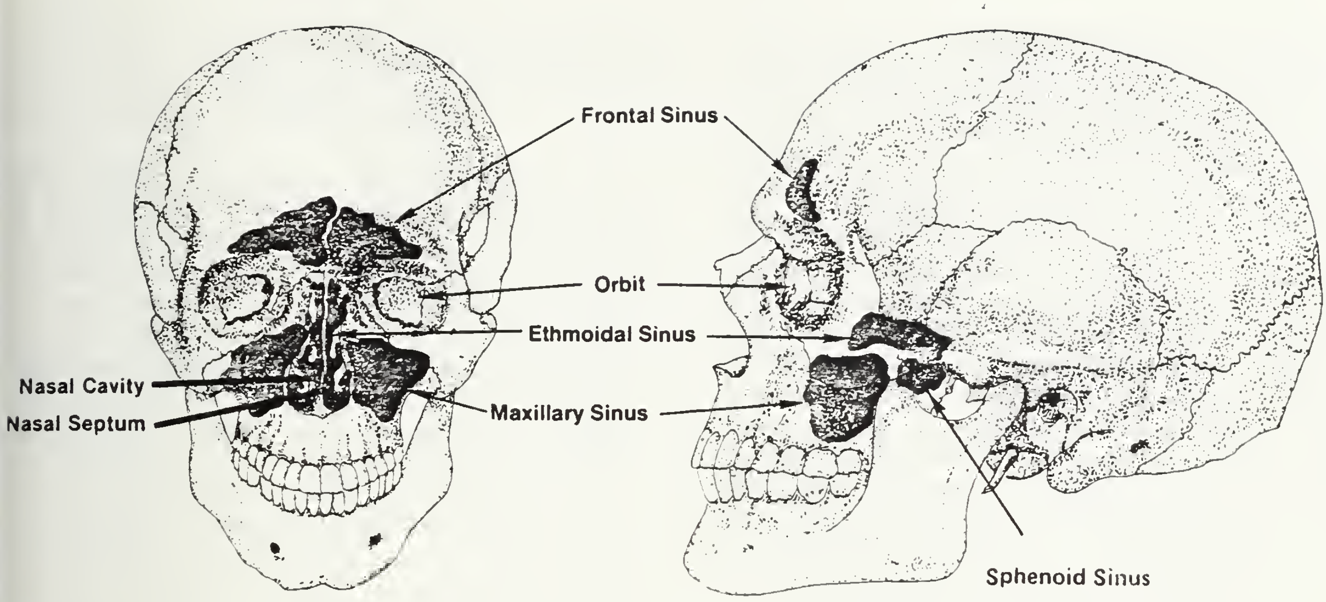


Figure 3-14. Frontal view of human skull with major sinus cavities projected on surface.

Lateral view of skull showing location of sinus cavities.

ıalance. If the space cannot be equalized (by swallow-ıg or blowing against a pinched-off nose), the dive nust be aborted.

'ooth Squeeze 3.8.3 Tooth Squeeze results when small pocket of trapped gas has been generated by ecay or is lodged under a poorly-fitted or cracked fill-ıg. If this pocket of gas is completely isolated, the ulp of the tooth or the tissues in the tooth socket can e sucked into the space causing pain. If additional as enters the tooth during descent and doesn't vent uring ascent the tooth may explode.

ːxternal Ear Squeeze 3.8.4 If a diver wears ear lugs, has an external ear infection, impaction of wax ı the ear canal, or a tight-fitting hood, he can develop n external ear squeeze. Gas trapped in the external anal remains at atmospheric pressure while the ex-ːrnal water pressure builds. The ear drum bows out-'ard in an attempt to equalize the pressure difference nd may rupture. The skin of the canal also becomes wollen and hemorrhagic. Considerable pain results.

revention of external ear squeeze is essential. Ear lugs must not be worn. In addition to creating the queeze, they may be forced deep into the canal. /hen a hooded suit must be worn, air (or water in ome types) must be allowed to enter the hood to qualize pressure in the ear canal.

Thoracic (Lung) Squeeze 3.8.5 In making a breathhold dive, it is possible to reach a depth at which the air held in the lungs will be compressed to a volume somewhat smaller than the normal residual volume of the lungs. At this volume, the chest wall becomes stiff and incompressible. Should the diver descend further, the additional pressure will be unable to compress the chest walls or elevate the diaphragm further and the pressure in the lung will become negative with respect to the external water pressure. Injury will take the form of squeeze. Blood and tissue fluids will be forced into the lung alveoli and air passages where the air is under less pressure than the blood in the surrounding vessels. This amounts to an attempt to relieve the negative pressure within the lungs by partially filling the air space with swollen tissue, fluid and blood. Considerable lung damage, therefore, results. If severe enough, it may prove fatal. If the diver descends still further, death will result from crushing of the chest walls, similar to the collapse if a sealed tin can which is lowered into deep water.

Theoretically, the average man with a total lung capacity of 6 liters could not breathhold dive beyond approximately 30 meters (4 ata) as the air in his lungs at that point would be compressed to the residual volume (1.5 liters, average value). A man with an exceptional lung capacity could exceed that depth, but would eventually reach his own limit. In 1968, the world record holder for breathhold skin diving was Navy Petty Officer Robert Croft who had an exceptional total lung capacity of more than 9 liters. During a

series of experimental dives, Croft reached 240 feet (73 meters) which is about 39 feet (12 meters) below his "computed" residual limit. He did not experience any symptoms of thoracic squeeze.

Face or Body Squeeze 3.8.6 If the air pressure in a surface-supplied face mask or helmet should suddenly become lower than that of the surrounding water — as in a failure of the air supply or from a rapid increase in depth — the tissues of the face or body can be seriously squeezed. This is a particular danger when working with the deep-sea diving dress, which encloses the head, neck and part of the upper chest in a rigid helmet. Under normal conditions, the pressure in the helmet (and in the diving dress) will be in equilibrium with the outside pressure. However, if the air pressure suddenly drops, the outside pressure could force the air in the suit and helmet back up the air hose. In doing so, the non-rigid dress will collapse, squeezing the diver's body into the incompressible helmet, and if the pressure differential is great enough, this condition can become fatal. To help prevent major body or face squeeze, all surface-supplied apparatus must be equipped with a safety non-return valve which will hold the gas in the suit at pressure in the event of a failure of the supply pressure. A diver may similarly become a victim of body and face squeeze if he should fall into deeper water without a corresponding increase in supply pressure. (See Chapter 6 for additional discussion.)

Face masks used with SCUBA, goggles, and certain types of exposure suits can lead to problems of squeeze under some conditions. The pressure in a face mask can usually be equalized by exhaling through the nose, but this is not true of goggles which offer no way to equalize pressure. Therefore, goggles should only be used for surface swimming. The most seriously affected tissues in an instance of face mask or goggle squeeze will be those of the eye and the eye socket. When using exposure suits, air may be trapped in a fold in the garment and may lead to some discomfort and possibly a minor case of hemorrhage into the skin from pinching.

Middle Ear Overpressure (Reverse Middle Ear Squeeze) 3.8.7 Expanding gas in the middle ear space during ascent ordinarily vents out through the Eustachian tube. If the tube becomes blocked, pressure in the middle ear relative to the external water pressure increases. The ear drum is bowed outward and causes pain. If the overpressure is significant, the ear drum may rupture which may cause the same symptoms as seen in ear drum rupture during descent.

The increased pressure in the middle ear may also affect nearby structures and produce symptoms of vertigo and inner earn damage (see 3.8.10) or, rarely, facial muscle weakness. It is extremely important to rule out arterial gas embolism or decompression sickness when these unusual symptoms of reverse middle ear squeeze occur during ascent or with surfacing.

Facial muscle weakness as a result of middle ear overpressurization (Alternobaric facial palsy) is a rare syndrome. In a few individuals, the anatomy of the middle ear is such that the blood supply to the facial nerve can be reduced by middle ear overpressure. Ten to thirty minutes of overpressure is required for symptoms to develop. The half of the face on the side of the affected ear becomes paralyzed. Sensation remains intact, however, since this is carried by another nerve, nausea and vertigo are usually also present. All symptoms subside spontaneously after the middle ear vents;

Diving with a cold or inability to equalize the ears will increase the likelihood of developing reverse middle ear squeeze. There is no uniformly effective action for clearing the ears on ascent. Valsalva maneuver will increase the pressure in the middle ear and should not be done on ascent. If pain in the ear develops on ascent, the diver should descend a few feet to relieve the symptoms and then begin ascent at a slower rate. Several such attempts may be necessary as the diver gradually works his way to the surface.

Sinus Overpressure (Reverse Sinus Squeeze) 3.8.8 A fold in the sinus-lining membrane, a cyst, or an outgrowth of the sinus membrane may act as a ball valve and prevent gas from leaving the sinus during ascent. As the sinus pressure increases, sharp pain in the area of the affected sinus results and will usually be sufficient to block further ascent. Pain is relieved immediately by descending a few feet. At this point, the diver should ascend at a more gradual rate. Several such descents and ascents may be necessary to reach the surface.

If the maxillary sinus is involved, the blood supply to the infraorbital nerve may be reduced. This will result in numbness of the upper gums and teeth, the upper lip, and part of the face overlying the sinus. Full sensation will return with venting of the sinus.

Overexpansion of the Stomach and Intestine 3.8.9 While a diver is under pressure, gas formation may take place within his intestines, or air may be swallowed and trapped in his stomach. On ascent this trapped gas expands and occasionally causes enough discomfort to require stopping until it can be expelled. Continuing ascent in spite of marked discomfort may

sult in actual harm. Chewing gum during a dive can use air swallowing and should therefore be avoided.

ner Ear Dysfunction and Vertigo 3.8.10 The iner ear contains no gas, so strictly speaking it is not ubject to barotrauma as a separate entity. However, e inner ear is located next to the middle ear cavity d is affected by those same conditions which proce middle ear barotrauma. As the gas in the middle r is compressed or expands without the relief norally provided by the Eustachian tube, the fluid and embranes of the delicate inner ear will be disturbed their function, and possibly physically torn as the essure gradient increases.

e inner ear has two functions. One portion, the chlea, (Figure 3-13) is the hearing sense organ and n produce symptoms of hearing loss and ringing in e ear (tinnitus) if damaged. The other part of the inr ear is the vestibular apparatus, which is the organ at senses balance and motion. Damage to the stibular apparatus may cause vertigo, which is the se sensation of a spinning type of motion. The diver ll feel that either he is spinning or the area around n is spinning while he may in fact be perfectly monless. One can usually tell this distinct sensation m the more vague complaints of dizziness or htheadedness, which may have any number of uses. Vertigo is usually specific for the inner ear or at part of the brain which analyzes inner ear input. rtigo has associated symptoms which may or may t be seen. These include nausea, vomiting, loss of lance, loss of coordination, and a rapid beating vement of the eyes (nystagmus). Besides inner ear rotrauma, vertigo may be caused by arterial gas emlism or Type II decompression sickness which is cussed in Chapter 8.

equent oscillations in middle ear pressure sociated with difficult clearing may lead to a condin of transient vertigo called alternobaric vertigo of scent. This vertigo usually follows a Valsalva neuver, often with the final clearing episode just as diver hits bottom. The vertigo is short-lived, but y cause significant disorientation.

ernobaric vertigo may also occur during ascent in sociation with middle ear overpressurization. In this tance the vertigo is often preceded by a feeling of ness or pain in the ear that is not venting excess ssure properly. The vertigo usually lasts just a few nutes, but may be incapacitating during that time. ief is abrupt and often accompanied by a hissing nd in the affected ear. Alternobaric vertigo of ascit will disappear immediately if the diver descends a few feet. Precisely how the middle ear overpressure affects the inner ear balance mechanism is not known.

A pressure imbalance between the middle ear and external environment may cause lasting damage to the inner ear if the imbalance is sudden or large. This type of inner ear barotrauma is often associated with rupture of the round or oval window but may also involve damage to many other structures of the inner ear.

There are three bones in the middle ear, the Malleus, the Incus, and the Stapes. The bones connect the tympanic membrane (eardrum) to the fluid filled structures of the inner ear (see Figure 3-13). The stapes is in direct contact with the inner ear and transmits the eardrum vibrations to the inner ear fluid through a membrane covered hole called the oval window. Another membrane covered hole called the round window connects the inner ear with the middle ear and serves to relieve pressure waves in the inner ear caused by movement of the stapes. Barotrauma can cause rupture of the round window membrane and of the oval window seal with associated leak of the inner ear fluid (perilymph). This conditions can occur as the consequence of an exertional effort during diving which in turn causes an increased intracranial pressure in the diver. If great enough, this pressure can be transmitted from the brain to the inner ear in such a manner as to explode through the round window membrane or through the oval window seal. Also, similar inner ear damage can result from the overpressurization of the middle ear by means of a too forceful Valsalva maneuver (holding the nose, closing the mouth and forcibly exhaling to clear the ears during descent). In addition to its desired effect of forcing gas up the Eustachian tube, the Valsalva maneuver increases the pressure of fluid within the inner ear. If the diver cannot clear, the Eustachian tube is collapsed because there is already a relative vacuum in the middle ear space. The combined forces could rupture the round or oval window membranes. It is also possible that a forceful Valsalva itself may damage the membranes by the implosive force of the gas entering the middle ear space. Symptoms of this condition include ringing or roaring in the affected ear (tinnitus), vertigo, disorientation, unsteadiness, and marked hearing loss. The diver may describe a bubbling sensation in the affected ear. The diagnosis of inner ear barotrauma should be considered whenever any inner ear symptoms occur during compression or after a shallow dive in which decompression sickness is unlikely. Inner ear barotrauma should not be treated with recompression if decompression sickness and air embolism can be ruled out as causing the vertigo (see Chapter 8). The treatment for inner ear barotrauma ranges from bed

rest to exploratory ear surgery depending on the severity of the symptoms. All suspected cases of inner ear barotrauma should be referred to an ENT (ear, nose, throat) physician as soon as possible.

PULMONARY OVERINFLATION SYNDROMES 3.9

Pulmonary overinflation syndromes represent a group of barotrauma related diseases caused by the expansion of gas trapped in the lung during ascent or overpressurization of the lung with subsequent overexpansion and rupture of the alveolar air sacs. The two main causes of alveolar rupture include: (1) excess pressure inside of the lung caused by positive pressure (e.g., pressing the purge button on a single hose regulator while taking a breath) or more commonly (2) failure of expanding gases to escape from the lung during ascent (e.g., voluntary or involuntary breathing holding during ascent or localized pulmonary obstructions which can cause air trapping such as asthma or thick secretions from pneumonia or a severe cold). The conditions which bring about these incidents are directly opposite to those which produce lung squeeze. They most frequently occur during submarine escape procedures or emergency ascent from dives made with lightweight diving gear or SCUBA.

The clinical manifestations of pulmonary overinflation depend on the location at which the free air collects. In all cases the first step is rupture of the alveolus with a collection of air locally in the lung tissues, a condition known as interstitial emphysema. Interstitial emphysema causes no symptoms unless further distribution of the air occurs. Gas may find its way into the chest cavity or the arterial circulation. These various conditions are depicted in Figure 3-15 and are discussed in the following sections.

Arterial Gas Embolism 3.9.1 Arterial air embolism is the most serious potential complication of diving caused by an excess of air pressure inside the lungs caused by holding the breath during ascent. For example, if an individual ascends to the surface from 100 feet, the air within his lungs will expand to four times its original volume. If this expanding air fills the lungs completely and is not allowed to escape, a pressure is built up within the lungs which is greater than the pressure surrounding the chest. This pressure overexpands the lung and ruptures its air sacs and blood vessels. Air is then forced into the pulmonary capillary bed, and bubbles are carried to the left chambers of the heart. From there, they are pumped out into the arteries. Any bubble which is too large to go through an artery will lodge and form a plug (embolus). The tissues beyond the plug will then be deprived of their blood supply. The consequences depend upon the area or organ where the blockage occurs. The brain is frequently involved; and when it is, the symptoms are usually extremely serious. Unless the victim is recompressed promptly to reduce the size of the bubble and permit blood to flow again, death may follow. The symptoms and treatment are discussed more fully in Chapter 8.

If one purposely tries to hold his breath during ascent, which should never be done operationally, a sensation of discomfort will be felt behind the breast bone and a feeling of actual stretching of the lungs will urge one to exhale at periodic intervals. A condition of fright, however, can apparently cause a spasm of the laryngeal muscles, sealing the main lung passageway, and thus bring about overexpansion of the lungs. Under these circumstances, death has occurred in ascent from depths of only 7 feet. On the other hand, safe ascents can be made from depths of more than 100 feet without any breathing appliance, provided the individual exhales continuously during his ascent. Every diver should make it an absolute rule always to breathe normally and continually during ascent. If he is out of air or his gear is not working and he cannot breathe, then he must exhale as he comes up.

Mediastinal and Subcutaneous Emphysema 3.9.2
INTERSITIAL EMPHYSEMA involves an entry of gas into the intersitial tissues in the lungs and, like gas embolism, it can arise as a tear of lung tissue if the diver fails to exhale adequately during ascent. This condition may accompany a gas embolism, or it may occur separately. Intersitial emphysema by itself causes no problems unless further gas expansion leads to mediastinal or subcutaneous emphysema. MEDIASTINAL EMPHYSEMNA is a condition whereby gas has been forced through torn lung tissue into the loose mediastinal tissues in the middle of the chest, around the heart, the trachea and the major blood vessels. SUBCUTANEOUS EMPHYSEMA results from the expansion of gas which has leaked from the mediastinum into the subcutaneous tissues of the neck. These three types of emphysema should not be confused with with the emphysema of old age or excessive smoking.

Pneumothorax 3.9.3 Pneumothorax is the result of air entering the potential space between the lung covering and the lining of the chest wall. In the usual form, called a simple pneumothorax, a one-time leakage of air from the lung into the chest partially collapses the lung causing varying degrees of respiratory distress. This normally improves with time as the air is

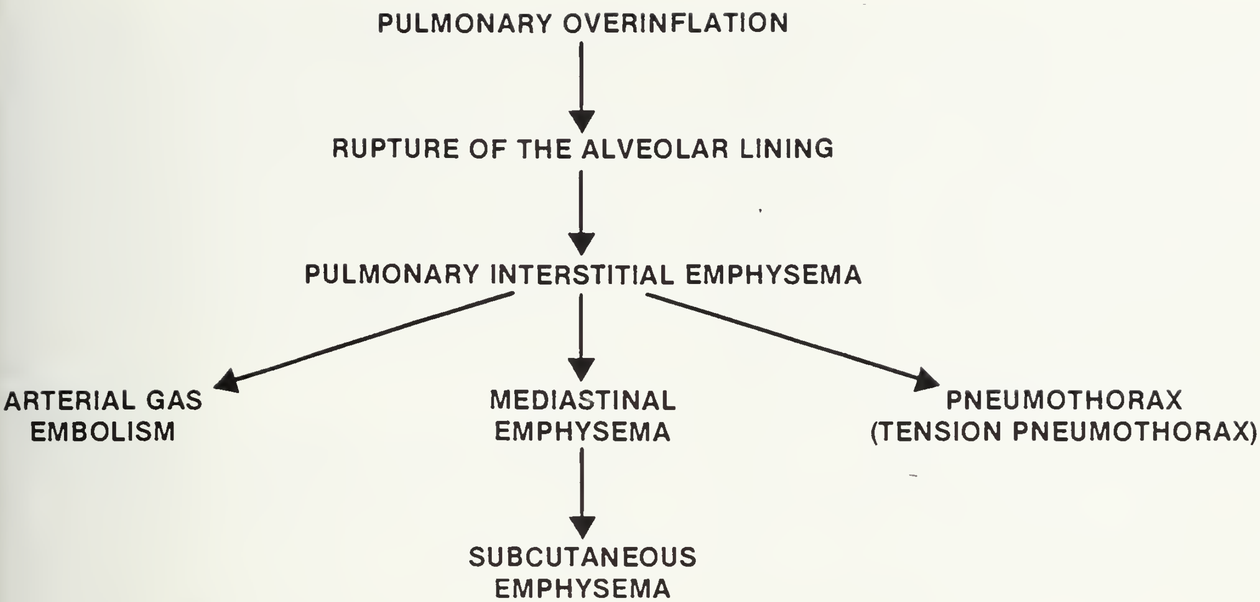


Figure 3-15 The Possible Consequences of Pulmonary Overinflation. Dissection of gas into the pulmonary interstitial tissue causes no symptoms unless further dissection occurs. If gas enters the arterial circulation, potentially fatal arterial gas embolism may occur. Localization to tissue under the skin causes emphysema. Pneumothorax occurs if gas accumulates between the lung and chest wall and if accumulation continues without venting, then Tension Pneumothorax may result.

absorbed. Sometimes if the degree of lung collapse is sufficient, the air must be removed by placement of a tube or catheter.

In certain instances, the damaged lung may allow air to enter but not exit the space between the lung and chest wall with successive breaths thus progressively enlarging the air pocket. This is called a tension pneumothorax due to the progressively increasing tension or pressure the expanding gas exerts on the lung and heart. If uncorrected, this situation will push on the involved lung completely collapsing it. The lung and soon the heart are pushed toward the opposite side of the chest and eventually circulation as well as respiration are compromised. This causes progressively more serious symptoms beginning with rapid breathing and ending in cyanosis, hypotension, shock and death unless corrected.

If a simple pneumothorax occurs in a diver under pressure, the air will expand according to Boyle's Law during ascent, creating a tension pneumothorax. The volume of air initially leaked into the chest and the remaining ascent distance determine the condition of the diver upon surfacing.

All serious cases of pneumothorax must be treated. This is done by removing the air with a catheter or tube inserted into the chest cavity between the ribs which is hooked to a one-way valve and a suction device. In the case of a a tension pneumothorax, this may be life saving. If a pneumothorax occurs in a diver, further ascent will be dangerous unless it is vented. As a temporary remedy, the symptomatic diver should be taken to the depth of relief and medical assistance sought.

INDIRECT EFFECTS OF PRESSURE 3.10

The conditions previously described come about because of differences in pressure which damage body structures in a direct, mechanical manner. The indirect or secondary effects of pressure are the result of changes in the partial pressure of individual gases in the diver's breathing medium. The mechanisms of these effects include saturation and desaturation of body tissues with dissolved gas and the modification of body functions by abnormal gas partial pressures.

Nitrogen Narcosis 3.10.1 Most divers who breathe air under pressure will at some depth experience nitrogen narcosis (sometimes called "rapture of the deep"). Symptoms of this problem generally begin to appear at about 100 fsw (30 meters) and progress rapidly beyond that depth. However, there is a wide range of individual susceptibility and some divers, particularly those experienced in deep operations with air, can often work as deep as 200 fsw (60 meters) without serious difficulty.

The symptoms, although quite specific, are not always apparent to the individual. The nitrogen produces an intoxicating effect similar to that of alcohol. The narcosis is characterized by a slowing of mental activity, fixation of ideas, slowing of reaction time and general euphoria. The diver finds it difficult to concentrate or to figure things out, and he may not be able to remember what he is supposed to do or even what he has already done. His reflexes and reaction times are slowed down. His observations will often be inaccurate, and he is likely to reach wrong conclusions about what to do.

The greatest hazard of nitrogen narcosis is that it may keep the diver from caring about the job or even about his own safety. An unusually stable experienced diver will be reasonably productive and safe at depths where others fail. He is familiar with nitrogen narcosis, is keenly aware of the extent to which it impairs him, and makes a strong conscious effort to carry on in spite of it. He knows that he must be unusually careful, that he must spend more time and effort making even the simplest observations and decisions, and that any relaxation of his conscious effort can lead to failure or a fatal blunder.

Divers who have had no recent exposure to breathing gases containing nitrogen at depths below 120 feet may be more susceptible to nitrogen narcosis than divers who have. As a diver accumulates exposures below this depth he gradually develops an increased tolerance to the narcotic effects of nitrogen. For example, a diver may find it almost impossible to function on his first air dive to 190 feet but will find his function greatly improved by the 3rd or 4th dive, even diving only once a day or every other day.

The mechanism by which nitrogen under pressure produces the narcotic effect is not known. The narcotic potency of nitrogen and other inert gases may be correlated with their relative solubility in fat (Meyer-Overton theory). The more soluble the gas, the greater the narcotic effect at a given partial pressure. For this reason, helium or neon—which are relatively insoluble in fat—are used as the inert gasses in deep diving.

Oxygen Poisoning 3.10.2 Partial pressures of oxygen in excess of that encountered at normal atmospheric conditions may be toxic to the body. Oxygen toxicity is dependent upon both the partial pressure and the exposure time. In the range of 0.2 to 0.5 atm O_2, no toxicity is usually detectable regardless of exposure time. At partial pressures above 0.5 atm, with exposure times varying from days to hours, lung (pulmonary) toxicity will occur. The first sign of pulmonary oxygen toxicity is mild pain or discomfort at the end of a deep inspiration. This will occur after a 24 hour exposure to a PO_2 of 0.6 ata (e.g. 60 fsw breathing air). Long exposures to higher levels of oxygen such as administered during Recompression Treatment Tables 4 or 7 may lead to a burning sensation on inspiration and progress to frank pain on inspiration. If exposure is continued, pulmonary function may decrease. During recompression treatments, pulmonary oxygen toxicity may have to be tolerated in patients with severe neurological symptoms in order to treat them adequately. In conscious patients, the pain experienced with inspiration will eventually limit further exposure to oxygen and the decreased pulmonary function will gradually return to normal after the exposure is terminated. If oxygen is administered to unconscious patients, there will be no pain to limit exposures and it is possible to subject them to exposures resulting in permanent lung damage. For this reason, care must be taken when administering 100% O_2 to unconscious patients.

At partial pressures of oxygen of 1.6 atm and greater, central nervous system (CNS) toxicity may occur before pulmonary symptoms. Onset of CNS symptoms such as convulsion can occur in hours or minutes. The susceptibility to central nervous system oxygen poisoning varies somewhat from person to person. The use of an "oxygen tolerance test" for diving training candidates is intended to identify those whose sensitivity to oxygen is usually high. Individual susceptibility will also vary from time to time, and for this reason divers who pass an oxygen tolerance test may experience CNS toxicity at a later time. A major external factor contributing to the development of oxygen poisoning is the presence of a high level of carbon dioxide in the breathing mixture resulting from absorbent failure, CO_2 in the helmet supply gas, or inadequate helmet ventilation in the face of heavy exertion.

Experience and experimental investigation have shown that most divers, when performing heavy exercise, will be in danger of CNS oxygen poisoning when the partial pressure of oxygen in the breathing mixture is 1.6 atmospheres or greater. The air diver seldom encounters oxygen partial pressures above this level since it represents a depth of over 200 fsw (61 meters) and problems of CO_2 retention and nitrogen narcosis tend to limit the maximum air depth. His greatest opportunity for being exposed to the potential of oxygen poisoning is during recompression treatment or surface decompression using oxygen. For this reason, it is essential that the diver be monitored constantly inside the chamber for the related symptoms of oxygen poisoning.

Sometimes early evidences of oxygen poisoning appear before convulsions. If recognized, these symptoms may provide sufficient warning to permit reduction in oxygen partial pressure and prevent the onset of more serious symptoms. The warning symptoms most often encountered, in the approximate order of their likelihood of occurrence, include:

- Muscular twitching—This usually appears first in the lips or elsewhere in the face, but it may affect any muscle.
- Nausea—This may come and go periodically.
- Dizziness
- Abnormalties of vision or hearing—Tunnel vision (loss of the ability to see things to the sides) is one of the more frequent visual symptoms.
- Difficulty in Breathing—The diver may have air hunger, may sense an increase in breathing resistance for no apparent reason, or may have trouble taking a full breath into his lungs.
- Anxiety and confusion
- Unusual fatigue
- Incoordination—Clumsiness, etc.

Not all of these symptoms will always appear and most of them are not exclusively symptoms of oxygen poisoning. Twitching is the clearest warning of oxygen toxicity, but it may occur late. The appearance of any one of these symptoms, however, usually represents a body signal of distress of some kind and should be heeded.

Convulsions are the most important consequence of poisoning with excess oxygen and may occur suddenly without being preceded by any other symptoms. During a convulsion, the individual loses consciousness; and his brain sends out uncontrolled and completely disorganized volleys of nerve impulses to his muscles. At the height of the seizure, all of the muscles are stimulated at once and lock the body into board-like stiffness. The brain soon fatigues, and the number of impulses drops off. In this phase, the random impulses to various muscles may cause violent thrashing and jerking for a minute or so. Sometimes, involuntary urination and defection, and occassionally erection and ejaculation, take place during the convulsion. After the convulsive phase, the brain is completely tired out; and "post-convulsive (postictal) depression" follows. During this phase, the patient is usually unconscious and quiet for a while, then semiconscious and very restless. He will then usually sleep off and on, waking up occasionally but not being fully rational. The phase of depression sometimes lasts as little as 15 minutes, but an hour or more is not uncommon. At the end of it, the individual will often become alert rather than suddenly and complain of no more than fatigue, muscular soreness, and possibly a headache. After an oxygen convulsion, the diver will usually remember clearly the events up to the moment when consciousness was lost but will remember nothing of the convulsion itself and little of the postictal phase.

Despite its rather alarming appearance, the convulsion itself is usually not much more than a strenuous muscular workout for the victim. In oxygen convulsions, even the possible danger of hypoxia during breathholding in the "stiff" phase is eliminated. The tongue may be chewed when the jaw takes part in the jerking phase, and once in a great while a bone will give way under the strain of the contracting muscles. The main dangers are from what may happen during the process. If convulsion occurs in a recompression chamber, one tender should be able to keep the man from thrashing against hard objects and hurting himself. Complete restraint of the movements is neither necessary nor desirable. The oxygen mask should be removed. It is not necessary to force the mouth open to insert a bite block while a convulsion is taking place. After the convulsion subsides and the mouth relaxes, keep the jaw up and forward to maintain a clear aiway until the diver regains consciousness. Breathing almost invariably resumes spontaneously.

In suit-and-helmet diving, convulsion might lead to blowup or squeeze; but bruises and a chewed tongue are more likely to be the only consequences. Bringing a diver up rapidly during the height of convulsion could possibly lead to air embolism. In the use of SCUBA, the consequences of convulsions are likely to be more serious, with drowning as the main danger. This is a situation where using the "buddy system" in self-contained diving can mean the difference between life and death.

Even if a man with oxygen poisoning continues to breathe oxygen, the convulsion will almost always cease in a few minutes and be followed by a quiet interval of several minutes. If the oxygen partial pressure is then lowered, there will seldom be a further seizure. Usually, the convulsive phase is over before any drug could be injected to stop the fit, and such treatment is necessary only in the extremely rare cases where convulsion continues after lowering the oxygen pressure.

If one of the early symptoms of oxygen toxicity occurs, the diver may still go on to convulse up to a minute or two after being removed from the high oxygen breathing gas. This is known as the "Off Effect". One should not assume that an oxygen convulsion will not occur unless the diver has been off oxygen for 2 to 3 minutes.

If a man with oxygen convulsions is prevented from drowning or otherwise injuring himself, he can expect to recover promptly and have no lasting effects. Nor will he be any more or less susceptible to oxygen poisoning in the future. He may be more inclined to think he has "warning symptoms" during subsequent exposures to oxygen, but this is most likely a psychological matter.

The actual mechanism of CNS oxygen toxicity remains unknown in spite of many theories and much research. From the diver's standpoint, prevention of oxygen poisoning is the most important thing. He should not use oxygen where there is no good reason for doing so. (For example, there is no point in charging open-circuit gear with oxygen.) When the use of oxygen is advantageous or necessary, he should apply sensible precautions like being sure the breathing apparatus is in good order, observing the depth-time limits, avoiding excessive exertion, and heeding abnormal symptoms if they appear.

Decompression 3.10.3 The average human body at sea level contains about one liter of dissolved nitrogen. All of the body tissues are saturated with nitrogen at a partial pressure equal to the partial pressure of nitrogen in the alveoli—about 570 mmHg (0.75 ata). If the partial pressure of nitrogen should change because of a change in the pressure of the composition of the breathing mixture, the pressure of the nitrogen dissolved in the body will attain a matching level. Additional quantities will be absorbed, or some of the gas will be eliminated depending on the partial pressure gradient until the nitrogen partial pressure in the lungs and in the tissues are in balance.

In accordance with Henry's Law, the amount of nitrogen which will be absorbed or released is directly proportional to the change in partial pressure. If one liter of nitrogen is absorbed at a pressure of one atmosphere, then two liters will be absorbed at two atmospheres, and three liters at three atmospheres.

The process of taking up more nitrogen is called absorption or saturation. The process of giving up nitrogen is correspondingly called elimination or desaturation. The chain of events is essentially the same in both of these processes even though the direction of change is opposite . In diving, we are interested in both; saturation when the diver is exposed to an increased partial pressure of nitrogen at depth, and desaturation when he returns to the surface. Basically, the same processes occur with helium and other "inert" gases as with nitrogen.

The sequence of events in the process of saturation can be illustrated by considering what will happen in the body of a diver taken rapidly from the surface to 100 feet of depth (see Figure 3-16). To simplify matters, we can say that the partial pressure of nitrogen in his blood and tissues on leaving the surface is roughly eight tenths (0.8) of one atmosphere. When he reaches 100 feet, his alveolar nitrogen pressure will be about 0.8 of 4 atmospheres or 3.2 atmospheres, while the blood and tissues remain temporarily at 0.8. The "partial pressure difference" or gradient between the alveolar air and the blood and tissues is thus $3.2 - 0.8 = 2.4$ atmospheres. This gradient is the "driving force" which makes the molecules of nitrogen move by diffusion from one place to another. Consider the following events and factors in the diver at 100 feet:

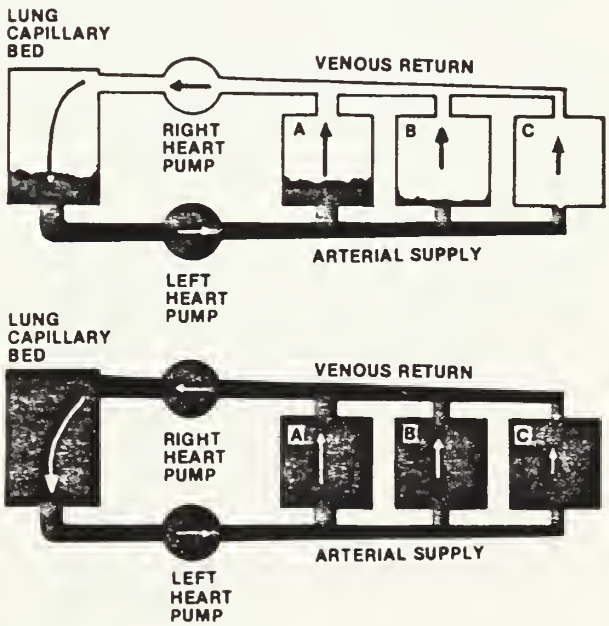


Figure 3-16. Saturation of tissues. Shading in diagram indicates saturation with nitrogen or helium under increased pressure. Blood becomes saturated on passing through lungs, and tissues are saturated in turn via blood. Those with large supply (like A) are saturated much more rapidly than those with poor blood supply (like C) or an unusually large capacity for gas, as fatty tissues have for nitrogen. In very abrupt ascent from depth, bubbles may form in arterial blood or in "fast" tissue (like A) even though body as a whole is far from saturation. If enough time elapses at depth, all tissues will become equally saturated, as shown in lower diagram.

(a) As blood passes through the alveolar capillaries, nitrogen molecules move from the alveolar air into the blood. By the time the blood leaves the lungs, it has reached equilibrium with the new alveolar nitrogen pressure. It now has a nitrogen tension of about 3.2 atmospheres and contains about four times as much nitrogen as it did before.

(b) When this blood reaches the tissues, there is a similar gradient; and nitrogen molecules move from the blood into the tissues until equilibrium is reached.

(c) The volume of blood in a tissue is relatively small compared to the volume of the tissue, and the blood can carry only a limited amount of nitrogen. Because of this, the volume of blood which reaches a tissue over a short period of time loses its excess nitrogen to the tissue without increasing the tissue nitrogen pressure very greatly.

d) When the blood leaves the tissue, the venous blood nitrogen pressure is equal to the new tissue nitrogen pressure. When this blood goes through the lungs, it again reaches equilibrium at 3.2 atmospheres.

e) When the blood returns to the tissue, it again loses nitrogen until a new equilibrium is reached.

f) As the tissue nitrogen pressure rises, the blood-tissue gradient decreases slowing the rate of nitrogen exchange. The rate at which the tissue nitrogen partial pressure increases, therefore, slows as the process proceeds. However, each volume of blood which reaches the tissue gives up some nitrogen and thus increases the tissue pressure somewhat until complete saturation, in this case at 3.2 atmospheres of nitrogen, is reached.

g) Tissues which have a large blood supply in proportion to their own volume have more nitrogen delivered to them in a certain amount of time, and therefore, approach complete saturation more rapidly than tissues which have a poor blood supply.

) If a tissue has an unusually large capacity for nitrogen, it will take longer for the blood to deliver enough nitrogen to saturate it completely. Nitrogen is about five times as soluble in fat as in water. Therefore, fatty tissues require much more nitrogen and much more time to saturate them completely than "watery" tissues do even if the blood supply is ample. A fatty tissue with a poor blood supply saturates very slowly indeed.

(i) In the diver at 100 feet, the blood continues to take up more nitrogen in the lungs and to deliver more nitrogen to tissues until all of his tissues have reached saturation at a pressure of 3.2 atmospheres of nitrogen. A few of his "watery" tissues which have an excellent blood supply will be almost completely saturated in a few minutes. Others, like fat with a poor blood supply and perhaps some watery tissues with an exceptionally meager blood flow, may not be completely saturated unless the diver is kept at 100 feet for 72 hours or longer.

(j) If he is kept at this depth of 100 feet until saturation is complete, the diver's body will contain about 4 times as much nitrogen as it did at the surface. If he is of average size and fatness, he contained about one liter of dissolved nitrogen at the surface and therefore will contain about 4 liters at 100 feet. Since fat holds about five times as much nitrogen as lean (watery) tissues, much of the diver's nitrogen content will be in his fatty tissue, and an obese diver will contain considerably more nitrogen than a lean one.

(k) An important fact about nitrogen saturation is that the process will require the same length of time regardless of the nitrogen pressures involved. For example, if this diver had been taken to 33 feet instead of 100, it would have taken just as long to saturate him completely and to bring his nitrogen pressures to equilibrium at that pressure. In this case, the original gradient between alveolar air and the tissues would have been only 0.8 atmospheres instead of 2.4 atmospheres. Because of this, the amount of nitrogen delivered to tissues by each round of blood circulation would have been smaller from the beginning. Less nitrogen would have to be delivered to saturate him at 33 feet, but the slower rate of delivery would cause the total time required to be the same.

If any other inert gas such as helium is used in the breathing mixture, the body tissues will become saturated with that gas in the same process. However, the time required to reach satuaration will be different for each gas.

The process of desaturation is the reverse of saturation (see Figure 3-17). If the partial pressure of the gas

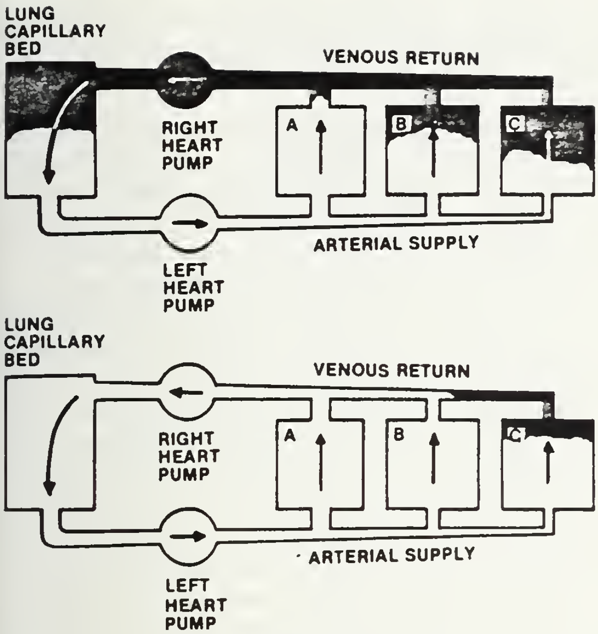


Figure 3-17. Desaturation of tissues. The desaturation process is essentially the reverse of saturation. When pressure of inert gas is lowered, blood is cleared of excess gas as it goes through lungs. Blood then removes gas from tissues at rates depending on amount of blood that flows through them each minute. Tissue with poor blood supply (as C in upper sketch) or large gas capacity will lag behind and may remain partially saturated after others have "cleared." (See lower diagram.) If dive is long enough to saturate such tissue, long decompression stops are required to desaturate it enough so that bubbles will now form in it on ascent.

in the lungs is reduced, either through a change in pressure or a change in the breathing medium, the new pressure gradient will induce the nitrogen to diffuse from the tissues to the blood, from the blood to the gas in the lungs, and then out of the body with the expired breath. Some parts of the body will desaturate more slowly than others for the same reasons that they saturate more slowly—poor blood supply, or a greater capacity to absorb the gas.

There is a major difference between saturation and desaturation. The body will accommodate large and relatively sudden increases in the partial pressure of the inspired gas without ill effect. The same is not true for desaturation, where a high pressure gradient (toward the outside) can lead to serious problems.

To illustrate—if a diver is working at depth of 100 feet, he will be under a total pressure of 4 atmospheres. The partial pressure of the nitrogen in the air he is breathing will be approximately 3.2 atmospheres (80% of 4 ata). If his body is saturated with nitrogen, the partial pressure of the nitrogen in his tissues will also be 3.2 atmospheres. If this diver were to quickly ascend to the surface the total hydrostatic pressure on his tissues would be reduced to 1 ata, whereas the tissue nitrogen tension would remain momentarily at 3.2 ata.

To have a dissolved-gas tension higher than the total pressure sounds like a physical impossibility. In a sense, it is. If a tissue is supersaturated with gas to this degree, the gas will eventually separate from solution in the form of bubbles. Bubbles of nitrogen forming in the tissues and blood result in a condition known as decompression sickness. These bubbles can put pressure on nerves, damage delicate tissues and block the flow of blood to vital organs. Symptoms may range from skin rash to mild discomfort and pain in the joint and muscles, to paralysis, numbness, hearing loss, vertigo, unconsciousness, and in extreme cases, death.

Fortunately, the blood and tissues can hold gas in supersaturated solution to some degree without serious formation of bubbles. This permits a diver to ascend a few feet without experiencing decompression sickness, while allowing some of the excess gas to diffuse out of the tissues and be passed out of his body. By progressively ascending in increments, and then waiting for a period of time at each level, the diver will eventually reach the surface without experiencing decompression sickness.

In actual diving practice, a diver very seldom will remain at depth long enough to become fully saturated with nitrogen. In a short dive, only those tissues which saturate rapidly will absorb any appreciable quantity of the gas, and they will desaturate easily. The standard decompression tables, developed from the research of Haldane and various Navy test programs, have been composed to provide guidelines for controlled decompression for a wide range of diving circumstances. The factors involved include such considerations as depth and bottom time of the dive, and whether or not the diver has made more than one dive within a 12 hour period, all of which will have some influence upon the quantity of nitrogen which will have been absorbed. The established decompression tables (Chapter Seven) must be followed rigidly to insure maximum diver safety. Changes in decompression procedure shall be permitted only under the advice of a Diving Medical Officer or in situations of extreme emergency.

Not all decompression is carried out necessarily by staged ascent to the surface. If the depth of the dive and the bottom are less than certain values, no stops or staged decompression is required; these are no-decompression dives. Also, within certain limits, a diver can be brought out of the water, repressurized in a chamber, and then decompressed on the surface. These surface decompression procedures are useful

'hen the surface support unit must move quickly, or 'hen the in-water conditions are particularly hazar-ous.

xygen decompression takes advantage of another ıctor about desaturation and bubble formation: It is e gradient or partial pressure difference between the ssues and the alveolar air which causes denitrogena-on of the tissues. It is the difference between tissue as tension and the total external pressure on the body hich is involved in bubble formation. If this distinction understood, the principle of oxygen decompression ould be clear. If the diver can breathe oxygen during s decompression stops, the nitrogen pressure in his veoli is reduced nearly to zero. This produces the rgest possible outward gradient for nitrogen and ings nitrogen out of the tissues even more rapidly an would breathing air at the surface. At the same ne, the total pressure on the body is maintained so at formation of bubbles is no more likely than it ould be during air-breathing at that stop. The result is tremendous saving of decompression time. The use oxygen for decompression is possible only at depths here oxygen can be breathed safely, and it is fre-ently not practical to supply a diver with oxygen. owever, oxygen decompression is an integral part of lium-oxygen diving technique, and it is also used utinely in connection with surface decompression.

High-oxygen" mixtures, those which contain a higher ncentration of oxygen than that of air, can metimes be used as the breathing medium to duce the decompression time required by dives. As s been shown, the need for decompression stops on cent stems from the fact that the body takes up inert s in solution while the diver is at depth. It does so cause of the increased partial pressure of the gas in e alveoli. The example of a diver breathing air at 100 et was used, and it was pointed out that his blood d tissues tend to reach equilibrium with the 3.2 at-osphere partial pressure of nitrogen in his alveoli. If s diver breathed a 60 percent nitrogen-40 percent ygen mixture at 100 feet instead of air, the nitrogen essure in his alveoli would be about 2.4 at-ospheres. This is the nitrogen pressure normally pre-nt when breathing air at 66 feet. With this breathing dium, a 100-foot dive would, therefore, require only much shorter decompression time of a 70-foot e.

ese oxygen rich mixtures increase the oxygen ten-n in the alveolus resulting in an increased arterial gen tension which is almost the same magnitude the decreased nitrogen tension. Since oxygen is idly consumed by body tissue, the resulting in-crease in tissue oxygen tension is insignificant. Thus not only has the tissue nitrogen tension been de-creased but the total tissue gas tension has been decreased as well. The increased inspired oxygen con-tributes little to tissue gas supersaturation and bubble formation; it is the inert gas (N_2 or He) tension which is important.

The extent to which oxygen rich mixtures can be used is limited by the fact that the partial pressure of oxygen is necessarily increased, and exposure to oxygen must be kept within safe limits of both pressure and time. Helium-oxygen diving technique normally involves the use of mixtures containing as much oxygen as is con-sidered safe for the dive involved in order to keep decompression time to the minimum. Therefore, the "mixture" principle is routinely applied in helium-oxygen diving.

Although all USN decompression procedures have been thoroughly tested in the laboratory and field, adherence to procedures and compliance with the standard tables does not guarantee that a diver will avoid decompression sickness. There are a number of individual differences and environmental factors that may influence development of decompression problems, in spite of all precautions. These include age, degree of obesity, excessive fatigue, lack of sleep, alcoholic indulgence, or anything which, in general, contributes to a poor physical condition or poor circulatory efficiency. Unusually heavy exertion during the dive and extremes of temperature also can have unfavorable effects. Exercise during decompres-sion, although it hastens elimination of inert gas from some tissues, often increases the incidence of decom-pression sickness. In addition, individual susceptibility may cause decompression sickness in healthy, fit divers with no apparent predisposing conditions.

Decompression Sickness 3.10.4 When a diver's blood and tissues have taken up nitrogen or helium in solution at depth, reduction of the external pressure on ascent can produce a state of super-saturation, as has been discussed. If the elimination of dissolved gas, via the circulation and the lungs, fails to keep up with the reduction of external pressure, the degree of supersaturation may reach the point at which the gas no longer can stay in solution. The situa-tion then resembles what happens when a bottle of carbonated beverage is uncapped.

Liberation of bubbles can apparently take place either in the blood or in a supersaturated tissue. A bubble in the bloodstream would produce symptoms by blocking circulation. Once in the tissue, it could put stretch or pressure on nerves or cause actual tissue damage.

The symptoms which result depend on the location and size of the bubble or bubbles. They consist of pain in joints, muscles, or bones when a bubble is in one of these structures. Bubble formation in the brain can produce blindness, dizziness, paralysis, and even unconsciousness and convulsion. When the spinal cord is affected, paralysis and/or loss of feeling can occur. Bubbles in the inner ear produce hearing loss and vertigo. Bubbles in the lungs can cause cough, shortness of breath, and hypoxia, a condition known as "chokes." Skin bubbles produce itching or rash or both. Unusual fatigue or exhaustion after a dive is probably also due to bubbles, but their location is not known. Many other symptoms can be caused by bubbles in unusual locations. Decompression sickness which affects the central nervous system (brain or spinal cord) or lungs can produce serious disabilities and may even threaten life if not treated promptly and properly. When other areas such as joints are affected, the condition may produce excruciating pain and lead to local damage if not treated, but life is seldom threatened.

Treatment of decompression sickness is accomplished by recompression—putting the victim back under pressure to reduce the size of the bubbles and to cause them to go back into solution. This is generally done in a recompression chamber but can sometimes be accomplished in the water if a chamber cannot be reached in a reasonable period of time. It must be done in a specified manner. Further discussion of the symptoms of decompression sickness and a complete discussion of treatment are presented in Chapter 8.

Prevention of decompression sickness is generally accomplished by following the decompression tables correctly. However, individual susceptibility or unusual conditions either in the diver or in connection with the dive will produce a small percentage of cases even when proper dive procedures are followed meticulously. To be absolutely free of decompression sickness under all possible circumstances, the decompression time specified would have to be far in excess of that normally needed. On the other hand, under ideal circumstances, some individuals can ascend safely in less time than the tables specify. This must not be taken to mean that the tables contain an unnecessarily large safety-factor. As a matter of fact, the tables generally represent the minimum decompression time which will permit average divers to surface safely from normal working dives without an unacceptable incidence of decompression sickness.

High Pressure Neurological Syndrome 3.10.5 High Pressure Neurological Syndrome (HPNS) is a derangement of central nervous system function that occurs on deep helium-oxygen dives. The cause is unknown. The clinical manifestations include nausea, fine tremor, imbalance, incoordination, loss of manual dexterity, and loss of alertness. Abdominal cramps and diarrhea may develop. In severe cases, a diver may develop vertigo, extreme indifference to his surroundings, and marked confusion such as the inability to tell the right from the left hand. HPNS is first noted between 400-500 feet and the severity appears to be both depth and compression rate dependent. With slow compression, depths of 1000 feet may be achieved with relative freedom from HPNS. Beyond that, some HPNS generally will always be present no matter how slow the compression rate. Attempts to block the appearance of the syndrome have included the addition of nitrogen or hydrogen to the breathing mixture and the use of various drugs. No method appears to be entirely satisfactory.

Compression Pains 3.10.6 Compression pains result from increases in external pressure surrounding the body. These pains affect the joints and may occur in almost any one. They have been seen in the knees, shoulders, fingers, back, hips, neck and ribs. Compression pains are deep aching pains similar to those of Type I decompression sickness. These pains may be accompanied by popping of joints or a dry gritty feeling within the joint.

Symptoms are dependent on depth, rate of compression and individual susceptibility. At rapid compression rates such as seen in air diving they may occur as shallow as 100 feet. In deep helium saturation dives with slower rates of compression they are more commonly seen below 300 feet. Below 600 feet, compression pains may occur even at very slow rates of compression. These pains may be severe enough to limit diver activity and may limit the travel rate and depths during downward excursions. Improvement is generally noted as time is spent at depth but on occasion these pains may last well into the decompression phase of the dive until shallower depths are reached. They can be distinguished from decompression sickness pain because they were present before decompressing and do not increase in intensity with decreasing depth.

The mechanism of compression pain is unknown but is thought to result from the sudden increase in tissue gas tension surrounding the joints causing fluid shifts and interfering with joint lubrication.

eatment of compression pains is accomplished with algesics and limitation of movement until they prove.

eathing Mediums 3.10.7 In view of the number of oblems which come up because of what a diver eathes, a summarizing discussion of the various ses which he can breathe may be useful.

R—Since it is the most available breathing medium, is naturally the one most commonly used in diving. s also the most satisfactory for most purposes but ogen narcosis limits the depth to which it can be ed. In most surface-supplied diving, air is the only ctical breathing medium to use. Special ar-gements are generally required to make other ses practical with air-hose equipment. In self-tained diving, air can be used safely only with de-nd type equipment; and the limited duration of the ply in this kind of rig can be a serious drawback ecially in deeper dives. The noise and bubbles of nand type gear can also be a serious disadvantage some diving operations.

YGEN—Except as employed in decompression cedures, oxygen is advantageous only when used h specially designed closed-circuit oxygen athing apparatus at shallow depth. The advantages lude freedom from bubbles, an almost completely nt operation, and maximum utilization of the gas. A all supply lasts a long time, and the duration of sup- is not altered by depth. The main disadvantage of gen is the limitation of safe depth and time of use. ygen is not thought to produce decompression kness, but decompression would not be a problem how within the depth-time range where oxygen can used.

ROGEN-OXYGEN MIXTURES—Air is the most mon nitrogen oxygen mixture. It contains about 79 cent nitrogen and 21 percent oxygen. An artificial ture with less nitrogen and more oxygen has the antage of requiring less decompression than air for ve of the same depth and duration. Safe, efficient of nitrogen-oxygen mixtures usually requires cial equipment, such as semiclosed or closed-uit types. As in the use of oxygen itself, the sibility of oxygen poisoning restricts the safe depth duration for use of "high oxygen" mixtures. ogen narcosis is generally not a problem because oxygen limits are generally more restrictive than e imposed by narcosis. Use of nitrogen-oxygen ures requires careful selection of percentage, -rate and the like. The expected depth, duration, type of work must be considered carefully.

HELIUM-OXYGEN MIXTURES—Avoidance of nitrogen narcosis in deep dives is the main purpose of using helium oxygen mixtures. The reduced density of the gas, however, also facilitates breathing and helps protect against CO_2 retention. Helium-oxygen can be used in demand type SCUBA, but the limited duration of supply at depth usually offsets the advantages. Use of helium-oxygen mixtures in semiclosed and closed-circuit is now commonplace.

As with nitrogen-oxygen mixtures, the percentage of oxygen must be kept within safe limits for the depth and duration of the dive to prevent oxygen poisoning. Incidental effects of helium-oxygen mixtures include a striking change in the diver's voice, and a more rapid loss of body heat in cold water.

HYDROGEN OXYGEN MIXTURES—Hydrogen is less dense, but more narcotic than helium. It has gained interest as a breathing medium because it is thought to produce milder symptoms of HPNS than helium. The main complication is the fact that hydrogen-oxygen mixtures are highly explosive unless the percentage of oxygen is kept very low. Hydrogen is currently used only in experimental diving.

NEON-OXYGEN MIXTURES—Neon is more dense than helium, but like helium appears free of narcotic properties. Expense has proved a major limitation to its use, and it is mainly of experimental interest.

ARGON-OXYGEN MIXTURES—Argon is both more dense and more narcotic than nitrogen. Its main use has been to accelerate the removal of nitrogen or helium from body tissues in the last stage of decompression. Argon saturates the body tissues more slowly than nitrogen or helium desaturate. The use of argon therefore can reduce the total inert gas pressure in the tissue. Argon has been used during experimental decompressions but is not currently used operationally.

PHYSIOLOGICAL HAZARDS FROM MUNITIONS 3.11

Divers frequently work with explosive material or, if involved in combat swimming, may become the target of explosives. An explosion is basically the violent expansion of a substance caused by the gases released during rapid combustion. One effect of an explosion is a shock wave that travels outward from the center, somewhat like the spread of ripples produced by dropping a stone into a pool of water. This shock wave propagating through the surrounding medium (whether air or water), passes along some of the force of the blast.

A shock wave moves more quickly, and is more pronounced in water than in air, because of the relative incompressibility of liquids. At the same time, since the human body is water, for the most part, and incompressible, an underwater shock wave will pass through the body with little or no damage to the solid tissues. However, the air spaces of the body, even though they may be in pressure balance with the ambient pressure, will not readily transmit the overpressure of the shock wave. As a result, the tissues which line the air spaces will be subject to a violent fragmenting force at the interface between the tissues and the gas.

The amount of damage to the body will be influenced by a number of factors. These include the size of the explosion, the distance from the site, and the type of explosive (some produce very rapid expansion while in others, the expansion progresses more slowly). In general, larger, closer and slower developing explosions are more hazardous. The depth of water and the type of bottom, which can reflect and amplify the shock wave, may also have an effect. Under "average" conditions, a shock wave of 300 psi or greater will cause injury to the lungs and the intestinal tract. A shock wave of this magnitude might be experienced from the explosion of a 1 pound (0.454 kg) charge, with the diver at 48 feet (15 meters) from the blast. A diver 48 feet from the explosion of a 600 pound (272 kg) charge would be subjected to a shock wave of 2,180 psi (6390 kg/cm^2).

The degree of injury in part will also be determined by the degree to which the diver's body is submerged. For an underwater blast, any part of the body which is out of the water will not be affected. Conversely, for an air blast, the deeper the diver, the better he will be protected. A diver who anticipates a nearby underwater explosion should try to get as much of his body out of the water as possible. If he must remain in the water, his best course of action is to float, face up, putting the thicker tissues of his back between the explosion and the vulnerable sites.

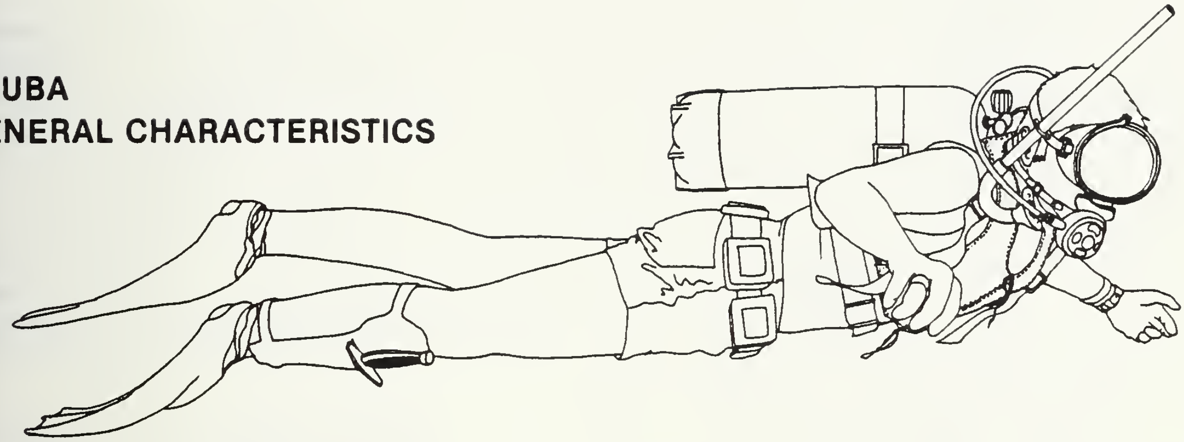
The maximum shock pressure to which a diver should be exposed is 50 psi. The safest and recommended procedure is to have all divers leave the water if an underwater explosion is planned or anticipated.

APPENDIX C

TYPES OF DIVING APPARATUS

SOURCE: REFERENCE # 4, U.S. NAVY DIVERS MANUAL VOL 1

SCUBA
GENERAL CHARACTERISTICS



Minimum Equipment—
- Open-circuit SCUBA
- Life preserver
- Weight belt and weights as required
- Knife and scabbard
- Face mask
- Swim fins
- Wrist watch
- Depth gauge

Principal Applications—
- Shallow water search
- Inspection
- Light repair and recovery

Advantages—
- Rapid deployment
- Portability
- Minimum support
- Excellent horizontal and vertical mobility
- Minimum bottom disturbances

Disadvantages—
- Limited endurance (depth and duration)
- Breathing resistance
- Limited physical protection
- Influenced by current
- Lack of voice communication

Restrictions—
- Working limits—
  - Within No Decompression Limits
  - Twin bottles required below 100 fsw
- Current—1 knot maximum
- Diving team—minimum 4 men

Operational Considerations—
- Standby diver required
- Small boat mandatory for diver recovery
- Moderate to good visibility preferred
- Ability to free ascend to surface required.

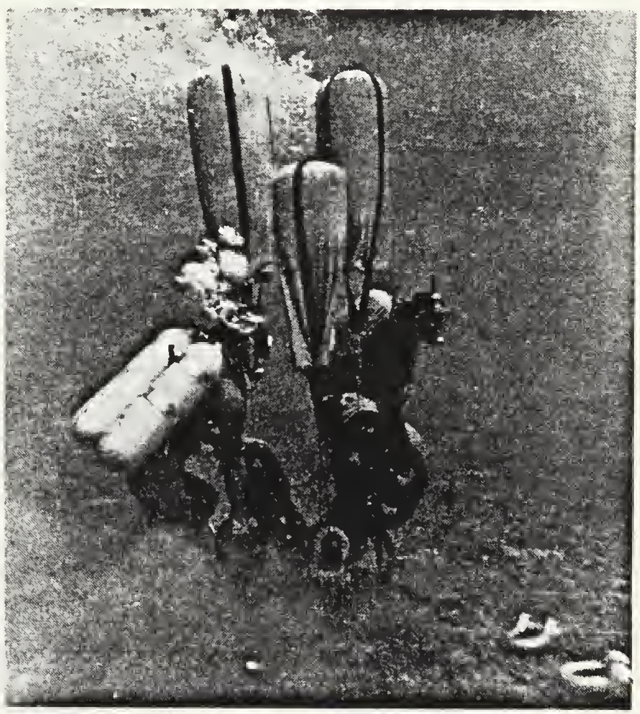


Figure 4-14 Open-Circuit SCUBA divers at work.

GHTWEIGHT DIVING
NERAL CHARACTERISTICS

iimum ipment—
MK 1 Mask or
Jack Browne mask
Wet suit
Weight belt
Knife
Swimfins or shoes
Surface umbilical

ncipal plications—
Shallow water search
Inspection and major ship repair
Light salvage

antages—
Unlimited by air supply
Good horizontal mobility
Voice and/or line pull
communications
Fast deployment

advantages—
Limited physical protection
Limited vertical mobility
Large support craft required

trictions—
Work limits—Jack Browne
Normal 40 feet/
No Decompression Table
Maximum 60 feet/
No Decompression Table
Work limit— MK 1 without come
home bottle
Maximum 60 feet
Work limit—MK 1 without open
bell
Maximum 190 feet/Standard
Air Decompression Table
Work limit—MK 1 with open bell
Maximum 190 feet/
Standard Air Decompression
Table and Surface
Decompression Table
Using Air
Current—2.5 knots maximum
with extra weights

rational siderations—
Ability to free ascend to surface
required, with exception noted
in Para. 6.3.5 and 6.4.4.1
Adequate air supply system
Standby diver required

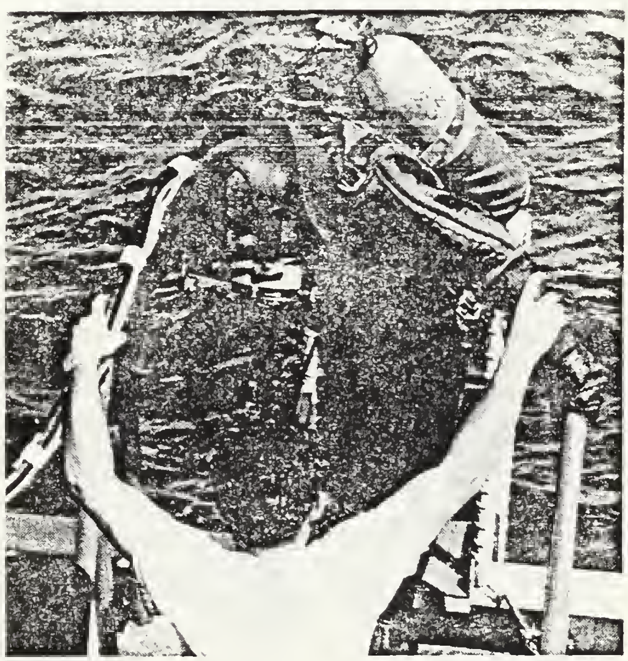
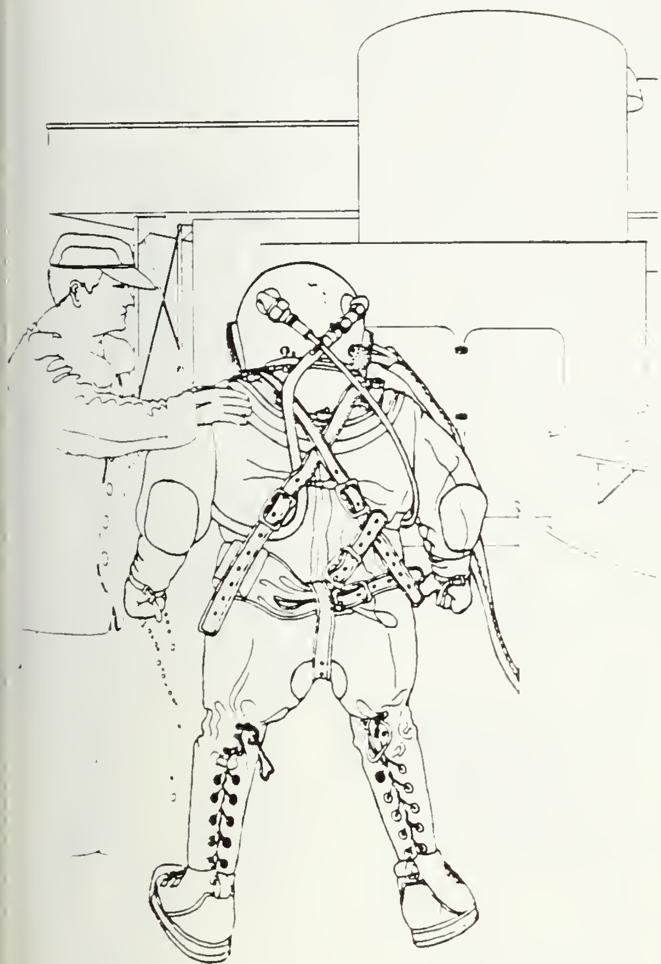


Figure 4-15 Diver using lightweight MK 1 diver's mask.

DEEP-SEA DIVING MK 5 GENERAL CHARACTERISTICS



Minimum Equipment—
Helmet and breastplate
Diving dress
Thermal underwear
Weight belt
Weighted shoes
Knife
Rubber cuffs and/or gloves
Surface umbilical

Principal Applications—
Deep diving operations
Heavy salvage and repair
Underwater construction

Advantages—
Unlimited by air supply
Maximum physical and thermal protection
Voice and line pull communication
Variable buoyancy

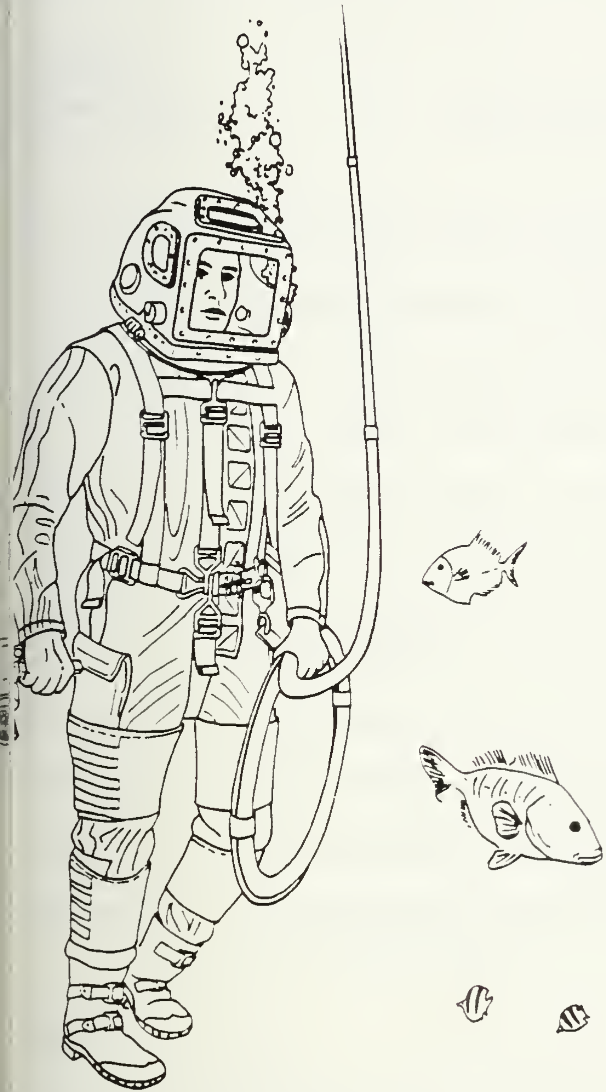
Disadvantages—
Slow deployment
Poor mobility
Large support craft and surface crew
Limited visibility
Limited logistic support

Restrictions—
Work limits—
Normal 190 feet/Standard Air Decompression Table and Surface Decompression Table Using Air
Maximum 285 feet (Exceptional Exposure)
Current—2.5 knots maximum with extra weights

Operational Considerations—
Adequate air supply system
Stand-by diver required
Medical officer and recompression chamber required below 190 feet
Exceptional exposures require approval of Commanding Officer or higher authority.

Figure 4-16 Diver in MK 5 deep-sea diving outfit entering the water.

P SEA DIVING MK 12
ERAL CHARACTERISTICS



ium ipment— Helmet assembly
Dry suit with lower breech ring
Outer garment
Thermal underwear
Jocking harness
Leg weights
Hip weights
Boots
Surface umbilical

cal lications— Deep diving operations
Heavy salvage and repair
Underwater construction

a ages— Unlimited by air supply
Maximum physical and thermal protection
Voice and line pull communication
Variable buoyancy

Disadvantages— Large support craft and surface crew

Restrictions— Work limits—
Normal 190 feet/Standard Air Decompression Table and Surface Decompression Table Using Air
Maximum 285 feet (Exceptional Exposure)
Current—2.5 knots maximum with extra weights

Operational Considerations— Adequate air supply system
Stand-by diver required
Medical officer and recompression chamber required below 190 feet.
Exceptional exposures require approval of Commanding Officer or higher authority.

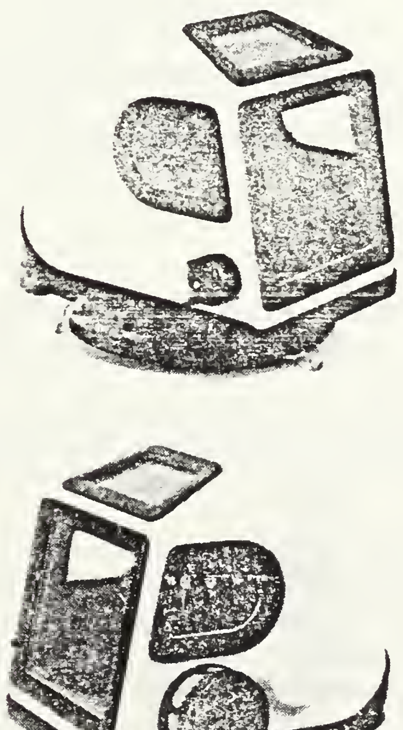


Figure 4-17 MK 12 Helmet Assembly

IORMAL AND MAXIMUM LIMITS FOR AIR DIVING

DEPTH ;w (METERS)	LIMIT FOR	NOTES (1 and 6)
40 (12.2)	Jack Browne Mask; normal working limit	
60 (18.3)	Open Circuit SCUBA: normal working limit	(2)
60 (18.3)	MK 1 Mask, max working limit without "come home bottle"	(4)
60 (18.3)	MK 1 Mask, with SCUBA air supply	
60 (18.3)	Jack Browne Mask: max working limit	(2)
190 (57.9)	Open Circuit SCUBA: max working limit	(2)
190 (57.9)	Diving without a medical officer and a recompression chamber at the scene	(3)
190 (57.9)	MK 1 Mask, max working limit	(3,4)
190 (57.9)	All divers except those qualified for mixed-gas diving	
190 (57.9)	Surface-supplied deep-sea (air) diving equip: normal working limit	(3,4)
285 (86.9)	Surface-supplied deep-sea (air) diving equip: max working limit: exceptional exposure	(3,5)

OTES:

These limits are based on a practical consideration of working time versus decompression time and oxygen-tolerance limits. These limits shall not be exceeded except by specific authorization from the Commanding Officer or from higher authority.

Under normal circumstances, do not exceed the limits of the No-Decompression Table. Dives requiring decompression may be made if considered necessary by the Commanding Officer of the diving command or higher authority. The total time of a SCUBA dive (including decompression) must never exceed the duration of the apparatus in use, disregarding any reserves.

A Diving Medical Officer is required on-scene for all air dives deeper than 190 fsw, where the maximum working depth of the diving apparatus may be exceeded, or for exceptional exposure air dives.

Exceptional and extreme exposure dives are not normally planned. Exceptional and extreme exposure tables, printed in RED in the standard Air Decompression Table, are computed for emergency situations only. Such situations defy complete assurance of safety, even if the correct decompression schedule is used.

Do not exceed the limits of the Standard Air Decompression Table for exceptional exposures.

For depth ranges and diving techniques not covered in the table refer to Vol. II Mixed Gas Diving.

ure 4-18 Normal and maximum limits for air diving

APPENDIX D

DIVING CONTRACTOR COST DATA

COURTESY OF OCEANEERING INTERNATIONAL, INC.

MORGAN CITY, LA

UNDERWATER SERVICES RATE SCHEDULE

EFFECTIVE DATE JANUARY 15, 1985

ADVANCED SYSTEMS

ATMOSPHERIC DIVING SYSTEM

The Atmospheric Diving Suit (ADS) enables a trained operator to work in water depths over 2,000 feet (610 meters) while remaining in an atmospheric or surface-pressure environment.

Oceaneering operates two types of ADS, the JIM and the WASP. The JIM has patented articulated arms and legs, while the WASP has the same arms, but utilizes thrusters for midwater work capability.

Both JIM and WASP place the operator in a natural, comfortable upright position which allows him to make working dives of several hours duration without excess fatigue.

Standard Package:

1	ADS Supervisor
4	ADS Operators
1	ADS Technician

1	JIM vehicle
1	WASP vehicle
2	Deployment winches
1	Handling system
1	Hydraulic power supply system
1	Van complete with system spares and consumables
1	T.V. system with video, audio and cassette recorder
1	Control van
1	Shallow air equipment package

Total day rate for above $5,500.00

Additional Personnel:

	12-Hour Day	Overtime Hour *
ADS Supervisor	$550.00	$90.00
ADS Operator	495.00	82.50
ADS Technician	470.00	77.00

Third party personnel provided by Oceaneering will be billed at cost plus 15%.

* Overtime rates also apply to the standard crews.

Continued

ATMOSPHERIC DIVING SYSTEM (Continued)

Usage:

A usage rate of $600.00 will be made for each working deployment of the ADS.

Additional Equipment:

Miscellaneous equipment as required for the scope of work will be invoiced in accordance with rates quoted in this rate schedule.

Specialized deep water optional equipment, such as 35 mm still photography, submersible hydraulic power packages and non-destructive testing equipment is available upon request.

REMOTE-OPERATED VEHICLES

HYDRA 1000 SYSTEM (Rated to 3000 Feet)

Oceaneering's HYDRA is a high thrust/payload capability work vehicle designed for medium work tasks. Bolt-on work packages can be attached to supplement the 7-function SC and 5-function manipulators on the vehicle. The HYDRA performs the full range of drilling and construction support work tasks and can be outfitted for precision inspection tasks. The HYDRA is also designed to perform underwater cleaning and inspection. The HYDRA is designed for high reliability and performance and is capable of working in the most extreme offshore conditions.

Standard Package:

1 Crewchief
1 Electronics Technician
1 Mechanical Technician

Color and black-and-white video
Deck winch
Generator
VHS recorders and monitors
Control van with tools
1 RMS 7-function manipulator
1 RMS 5-function manipulator

Total day rate for above.................. $4,500.00*

* Day rate is inclusive of tethers, consumables and maintenance items for normal operations. It does not include videotapes.

Optional Equipment:

Photographic: 35 mm still camera with strobe	
for 2000' operation	$300.00 per day
Film and processing	Cost plus 15%
Cathodic protection (silver-silver chloride half-cell)	Cost plus 15%
Ultrasonic test gear	Price on request
Sonar	Price on request
Hydraulic impact wrench	$ 75.00
Hydraulic grinder	75.00
Hydraulic buffer	75.00
AX, VX ring installation tool	50.00
High pressure salt water pump	125.00
Low pressure salt water pump	85.00
Current meter	Price on request
Temperature sensor	Price on request
Bottom sampler	25.00
Pipe tracking	Price on request
Leak detection	Price on request
Stereo 35 mm	350.00

Continued

REMOTE-OPERATED VEHICLES (Continued)

HYDRA 1000 SYSTEM

Personnel:

	12-Hour Day	Overtime Hour *
Crewchief	$495.00	$82.50
Electronics Technician	470.00	77.00
Mechanical Technician	440.00	73.00
Acoustics Technician	470.00	77.00
Project Manager	550.00	90.00

Third party personnel provided by Oceaneering will be billed at cost plus 15%.

* Overtime rates also apply to the standard crews.

REMOTE-OPERATED VEHICLES (Continued)

RECON J SYSTEM (Rated to 1200 Feet)

Oceaneering's Recon J is a highly mobile undersea vehicle designed for high reliability, performance and ease of operation. The Recon J is equipped with either a color or black-and-white video camera. The Recon J handling system is skid-mounted and uses a U-boom to deploy the tether management system (TMS) and ROV. The TMS deploys and recovers 400 feet of neutrally buoyant, protected tether, and is controlled by the vehicle operator. The Recon J uses hardwire umbilicals to transmit power and data to the vehicle from control circuitry located on the surface, which minimizes subsea electronics, thereby increasing reliability and reducing maintenance.

Standard Package:

1 Crewchief
1 Electronics Technician
1 Mechanical Technician

Color and black-and-white video cameras
Deck winch with subsea deployment cage
Generator
VHS recorders and monitors
Control van with tools

Total day rate for above.................. $3,300.00*

* Day rate is inclusive of tethers, consumables and maintenance items for normal operations. It does not include videotapes.

See Optional Equipment and Additional Personnel on Page 7.

REMOTE-OPERATED VEHICLES (Continued)

RECON SJ SYSTEM (Rated to 1500 Feet)

Oceaneering's Recon SJ is a high thrust/payload capability work vehicle designed for light and medium-duty work tasks. Bolt-on work packages can be attached to the Recon SJ to do numerous work tasks, including anode delivery and attachment, object retrieval and replacement to 700 lbs., debris removal, underwater cleaning and manipulative tasks. The Recon SJ is designed for high reliability, performance and ease of operation.

Standard Package:

1 Crewchief
1 Electronics Technician
1 Mechanical Technician

Color and black-and-white video cameras
Deck winch with subsea deployment cage
Generator
VHS recorders and monitors
Control van with tools

Total day rate for above.................. $3,680.00*

* Day rate is inclusive of tethers, consumables and maintenance items for normal operations. It does not include videotapes.

See Optional Equipment and Additional Personnel on Page 7 .

REMOTE-OPERATED VEHICLES (Continued)

Optional Equipment:

Photographic: 35 mm still camera with strobe	
for 2,000' operation	$300.00 per day
Film and processing	Cost plus 15%
Cathodic protection (silver-silver chloride half-cell)	Cost plus 15%
Ultrasonic test gear	Price on request
Manipulator (2-function)	$175.00 per day
Sonar	Price on request

Specialized tools:

* It is our intention to develop remote vehicles into specialized tools capable of performing a wide range of subsea functions. We welcome the opportunity to discuss any upcoming requirements of our clients for which a vehicle can be modified to perform.

  Advanced Work System technicians are available to consult with client engineers on new designs or modifications to existing systems. When new or modified equipment is built by Oceaneering personnel, it will be charged to the client on a cost plus 15% basis. Unless specifically agreed upon otherwise, these new developments become the sole property of Oceaneering.

* The adaptation of existing tools to an inspection system will be charged on a cost plus 15% basis.

Additional Personnel:

	12-Hour Day	Overtime Hour *
Crewchief	$495.00	$82.50
Electronics Technician	470.00	77.00
Mechanical Technician	440.00	73.50
Acoustics Technician	470.00	77.00
Project Manager	550.00	90.00

Third party personnel provided by Oceaneering will be billed at cost plus 15%.

* Overtime rates also apply to the standard crews.

REMOTE-OPERATED VEHICLES (Continued)

ACOUSTICS

RS-902 ACOUSTIC POSITIONING UNIT (Built by Honeywell)

Standard Unit includes:

1 Crewchief

Display unit
Control electronics
Hydrophone with mount
Vertical reference unit
2 Mini-beacons (8 hours each)

Total day rate for above.................. $1,200.00

RS-902 PRECISION POSITIONING SYSTEM

In addition to items in the Standard Unit, above, the Precision Positioning System includes:

3 Mini-floater beacons
3 20-day battery packs
Remote display monitor
HP-85 computer
RS-232 interface and software

Total day rate for above.................. $1,800.00

Optional Acoustic Equipment:

Mini-floater (no battery pack)	$ 35.00
10-day battery pack	Cost plus 15%
20-day battery pack	Cost plus 15%
45-day battery pack	Cost plus 15%
Mini-beacon (8-hour)	$ 40.00
HP-85 computer	125.00
HP-flatbed plotter	100.00
Remote monitor	15.00

Long-life, Depth Sensor or other special beacons can be provided on request.

OCEAN ARMS BELL

Oceaneering's manipulator bells provide a comfortable one-atmosphere environment in which two men can travel to 3,000-foot water depths to carry out general inspection and drilling rig support tasks. The bells are equipped with "ARMS", a unique manipulator system.

The manipulator system consists of two primary components: a "master-controller" and a "slave-manipulator" which are controlled from within the bell. As the operator moves the master-controller, his motions are duplicated by the slave-manipulator which performs the work outside the bell. A portion of the forces encountered by the slave are fed back to the master-controller offering a high degree of responsiveness and control. An additional grabber-type manipulator assists the force feed-back ARMS and holds the bell in position.

Oceaneering's Ocean ARMS Bells are available in depth capabilities of 1,800 or 3,000 feet.

Standard Package:

1 Supervisor
2 Senior Pilots/Technicians
2 Pilots/Technicians
1 Diver

ARMS bell with force-feedback and grabber-type manipulators
Handling system with winch and umbilical
Control/parts van
Generator/hydraulic van
Battery/workshop van
Videotape system
System interconnects, h.p. oxygen sypply
Shallow air diving package

Total day rate for above.................. $4,800.00

Optional Equipment:

Subsea tooling requirements will be determined by the scope of work. However, each system is complemented by a variety of tools and adapters for performing numerous subsea tasks.

Additional Personnel:

	12-Hour Day	Overtime Hour *
Supervisor	$550.00	$90.00
Senior Pilot/Technician	495.00	82.50
Pilot/Technician	470.00	77.00
Diver	385.00	42.00
Acoustical Technician	470.00	77.00

Third party personnel provided by Oceaneering will be billed at cost plus 15%.

* Overtime rates also apply to the standard crews.

INVOICING GUIDELINES

Mileage:

Automobile	$ .70/mile
Carry-all/van	.90/mile
¾-ton pick-up	.80/mile
1-ton flatbed truck	1.20/mile
1-ton truck with mini-float	1.90/mile
2½-ton truck with 20' bed	2.25/mile

Driver: First 8 hours	$15.00/hour
Overtime hour after 8 hours	22.50/hour

Third party transportation or handling .... Cost plus 15%

Crane or dock service provided by customer or charged at........ Cost plus 15%

Mobilization:

Yard labor for load-out and load-in of equipment will be charged at $12.00 per hour per person during normal working hours and $18.00 per hour per person outside normal working hours. Oceaneering yard cherry picker will be charged at $50.00 per hour. Oceaneering yard 100-ton crane with two riggers will be charged at $150.00 per hour. There will be a 2-hour minimum for the cherry picker and 100-ton crane.

Subsistence:

Subsistence when provided by Oceaneering .... Cost plus 15%

Video:

Videotape editing........ Price on request

Consulting:

Crewchiefs and Senior Technicians are available for consultations.

Onshore consulting, 8-hour minimum day rate........ $450.00

Reports:

Reports prepared onshore will be charged as per personnel used, in accordance with the schedule of rates. Binding and outside services will be charged at cost plus 15%.

INVOICING GUIDELINES (Continued)

Invoicing Provisions:

1. Advanced systems are headquartered at our Morgan City facility. Mobilization and demobilization are charged to the job site from this location, unless otherwise specified.

2. All equipment day rates are as stated on the basis of a 24-hour day. Crew members are included in the rate as working a 12-hour day.

3. Our equipment requires approximately one (1) hour pre-dive and one (1) hour post-dive maintenance to assure that the equipment is kept in optimum working condition. Such time will be considered as hours worked.

4. Overtime for crew members (beyond the 12-hour work day) will be charged at overtime rates.

5. The cost for positioning and recovery of subsea beacons, or replacements, if not recovered, will be charged to the client at cost plus 15%.

6. Any special equipment requested by the client will be charged at cost plus 15%.

7. Unless otherwise stated, equipment will be billed at full rate during mobilization and demobilization activities.

8. An acoustic tracking system is required for all "live boat" operations, such as pipeline inspections, bottom surveys, etc. When this condition exists, the day rate of the acoustic tracking system will be added to the rate of the advanced system.

9. In the event an advanced system becomes fouled, the cost of the retrieval will be billed to the client.

10. All equipment lost or damaged, when not due solely to the negligence of the contractor, will be billed to the client at cost plus 15%.

11. If a malfunction occurs on an advanced system, the first 12 hours of down time will be charged to the client. After this period, the rental rate automatically stops until the unit is repaired.

12. All consumables and any third party equipment or services contracted for on behalf of the client will be invoiced at our cost plus 15%.

13. If a job is cancelled after mobilization begins, hours incurred with a minimum eight((8) hour day will be billed for the vehicle crew plus yard labor and all third party charges incurred.

14. Workable sea states will be decided by the Supervisor on site.

15. Payment of all undisputed invoices is due within 30 days of receipt.

16. All customs, duties and import taxes will be invoiced for at cost plus 15%.

17. Equipment and personnel rates are portal-to-portal unless otherwise agreed upon.

SATURATION DIVING

BELL BOUNCE TO 400 FEET

Personnel requirement for each project will be based on the scope of work.

Minimum Personnel:

2 Supervisors
4 Divers
3 Bell Technicians
5 Tenders

Equipment:

One (1) complete bell bounce system to include one (1) 2-man bell, mating lock, at least one (1) 2-man living chamber, handling system, control van with mixed gas and air consoles, hot water system and all radios, hoses, whips, and auxiliary equipment to operate the system, together with necessary surface support diving equipment.

Day Rate for above Minimum Personnel and Equipment $7,065.00*

* Surface depth premium, surface personnel overtime, miscellaneous equipment as required for scope of work, and consumables will be invoiced in accordance with rates quoted in this rate schedule.

Offshore work platform can be supplied by client or Oceaneering will supply at cost plus 15%.

TWO-MAN SATURATION TO 600 FEET

Personnel requirement for each project will be based on the scope of work.

Minimum Personnel:

2	Supervisors
2	Saturation Divers
1	Surface Diver
4	Bell Technicians
6	Tenders

Equipment:

One (1) complete saturation system to include one (1) 2-man bell, mating lock, at least one (1) 2-man living chamber, handling system, control van with mixed gas and air consoles, environmental control unit, hot water system and all radios, hoses, whips, and auxiliary equipment to operate the system, together with necessary surface support diving equipment.

Day Rate for above Minimum Personnel and Equipment................$12,420.00*

There will be no additional charge for depth premium for divers in saturation as this is included in the saturation rates.

*Surface depth premium, surface personnel overtime, miscellaneous equipment as required for scope of work, and consumables will be invoiced in accordance with rates quoted in this rate schedule.

Offshore work platform can be supplied by client or Oceaneering will supply at cost plus 15%.

FOUR-MAN SATURATION TO 600 FEET

Personnel requirement for each project will be based on the scope of work.

Minimum Personnel:

- 2 Supervisors
- 4 Saturation Divers
- 2 Surface Divers
- 4 Bell Technicians
- 6 Tenders

Equipment:

One (1) complete saturation system to include one (1) 2-man bell, mating lock, at least one (1) 4-man living chamber, handling system, control van with mixed gas and air consoles, environmental control unit, hot water system and all radios, hoses, whips, and auxiliary equipment to operate the system, together with necessary surface support diving equipment.

Day Rate for above Minimum Personnel and Equipment................ $16,140.00*

There will be no additional charge for depth premium for divers in saturation as this is included in the saturation rates.

*Surface depth premium, surface personnel overtime, miscellaneous equipment as required for scope of work, and consumables will be invoiced in accordance with rates quoted in this rate schedule.

Offshore work platform can be supplied by client or Oceaneering will supply at cost plus 15%.

SIX-MAN SATURATION TO 600 FEET

Personnel requirement for each project will be based on the scope of work.

Minimum Personnel:

2	Supervisors
6	Saturation Divers
2	Surface Divers
4	Bell Technicians
6	Tenders

Equipment:

One (1) complete saturation system to include one (1) 2-man bell, mating lock, at least one (1) 6-man living chamber, handling system, control van with mixed gas and air consoles, environmental control unit, hot water system and all radios, hoses, whips, and auxiliary equipment to operate the system, together with necessary surface support diving equipment.

Day Rate for above Minimun Personnel and Equipment $19,440.00*

There will be no additional charge for depth premium for divers in saturation as this is included in the saturation rates.

*Surface depth premium, surface personnel overtime, miscellaneous equipment as required for scope of work, and consumables will be invoiced in accordance with rates quoted in this rate schedule.

Offshore work platform can be supplied by client or Oceaneering will supply at cost plus 15%.

SATURATION DIVING OVER 600 FEET

ing has been instrumental in diving research and decompression table have participated in deep diving studies to 1600 fsw and conducted open water in excess of 950 fsw in the Gulf of Mexico.

f diving operation requires highly skilled personnel as well as sophisticated ire available for immediate call-out to 1000 fsw. Systems to 1500 fsw can be uest.

g's safety regulations require that our regional Safety Officer and/or company ent during phases of the diving operations. The total crew size and type of may vary depending on the water depth and scope of work to be performed.

quest.

INVOICING GUIDELINES

See pages 27 to 30 of Surface Diving.

SURFACE DIVING

LABOR

Air Diving - Onshore Rates *

	8-Hour Day	Overtime Hour
**Diver	$220.00	$42.00
Tender	115.00	22.00
Diver/Tender Team	335.00	64.00
Superintendent/Project Manager	330.00	62.00
Diving Supervisor	280.00	53.00
***Underwater Welder/Diver	360.00	65.00

Air Diving - Offshore Rates *

	12-Hour Day	Overtime Hour
Diver	$385.00	$42.00
Tender	200.00	22.00
Diver/Tender Team	585.00	64.00
Superintendent/Project Manager	580.00	62.00
Diving Supervisor	490.00	53.00
***Underwater Welder/Diver	625.00	65.00

Mixed Gas Diving - Offshore Rates *

	12-Hour Day	Overtime Hour
Diver	$420.00	$45.00
Tender	200.00	22.00
Diver/Tender Team	620.00	67.00
Superintendent/Project Manager	580.00	62.00
Diving Supervisor	530.00	57.00
***Underwater Welder/Diver	645.00	69.00
Mixed Gas Manifold Operator	445.00	50.00
Bell Technician	425.00	45.00

* Specialized personnel will be quoted separately on request.

**Above rate includes basic equipment for one diver: One 16 cfm compressor, volume tank and dive hose, radio, air manifold and ladder. For additional diving equipment and tools refer to "Equipment Rental Schedule".

***Specialized and coded welding.

LABOR (Continued)

Depth Premium - Air and Mixed Gas Diving

Depth in Feet	Day Rate/Foot/Dive
0 - 50	No charge
51 - 100	$1.50
101 - 150	3.00
151 - 200	4.50
201 - 250	6.00
251 and deeper	7.50

There will be only one depth premium charge for the deepest dive per day per diver regardless of the number of dives each diver makes in each day. Depth premiums do not apply to divers in saturation.

Penetration Pay

There will be a penetration charge of $2.00 per foot per man, each day, based on the deepest penetration made inside an enclosed structure with limited access. Such charges are in addition to any depth charges.

Mobilization and Demobilization Pay

Yard labor for load-out and load-in of equipment will be charged at $12.00 per hour per person during normal working hours and $18.00 per hour per person outside normal working hours. Oceaneering yard cherry picker will be charged at $50.00 per hour. Oceaneering yard 100-ton crane with two riggers will be charged at $150.00 per hour. There will be a 2-hour minimum for the cherry picker and 100-ton crane.

Report Preparation

Comprehensive report preparation time will be charged at the hourly rate of $25.00. Third party drafting services or photographic processing will be invoiced at cost plus fifteen 15%.

EQUIPMENT PACKAGES

The following equipment lists meet minimum requirements. Additional equipment needed due to job requirements will be furnished in accordance with published rates.

Shallow Air Equipment Package - 0 to 60 Feet (No Decompression Diving)

*Note: Decompression diving requires decompression chamber with compressor.

2	Compressors, diesel, 25cfm
2	Volume tanks
2	Air filter systems, high pressure microparticle, and spares
1	Air manifold control system with interconnects
2	Dive hoses, 300', with strength member, communication line, and pneumofathometer hose
3	Radios, air communication with headset
1	Deck-connect ladder
1	Set standard Oceaneering shallow-water spares
1	Set standard decompression tables
1	OSHA first aid kit

Total day rate for above.................... $260.00

*Total day rate - decompression diving $450.00

Total weight.......................... 1,500 pounds

Deep Air Equipment Package - 61 to 190 Feet

1	Decompression chamber, standard double-lock, with interconnects
1	Compressor, diesel, 90 cfm
1	Compressor, diesel, 120 cfm
2	Volume tanks
2	Air filter systems, high pressure microparticle, and spares
1	Air manifold control system with interconnects
2	Dive hoses, 600', with strength member, communication line, and pneumofathometer hose
4	Radios, air communication with headset
2	Emergency ascent bottles with regulators
1	Deck-connect ladder
1	Equipment box containing standard Oceaneering diving gear
1	Set standard intermediate decompression tables
1	Set full service technical manuals
1	OSHA first aid kit

Total day rate for above.................... $625.00

Total weight......................... 15,000 pounds

EQUIPMENT PACKAGES (Continued)

Gas Equipment Package - 191 to 220 Feet

1	Decompression chamber, standard double-lock, with interconnects
2	Dive air compressors, high volume, with volume tanks
2	Air filter systems, high pressure microparticle, and spares
1	Oxygen analyzer, Teledyne
1	Helium mixed gas control system, multiple-diver, with interconnects
2	Helium communication unscramblers with headset
2	Radios, air communications with headset
3	Diving hoses, 600', with strength member, communication line, and pneumofathometer hose
2	Emergency ascent bottles with regulators
1	Deck-connect ladder
1	Equipment box containing standard Oceaneering diving gear
1	Set Oceaneering standard advanced decompression tables
1	Set full service technical manuals
1	OSHA first aid kit

Total day rate for above.................. $1,190.00

Total weight.......................... 26,000 pounds

Gas Equipment Package, Class II Bell - 221 to 300 Feet

1	Class II bell with handling system and umbilical
1	Decompression chamber, standard double-lock, with interconnects
2	Dive air compressors, high volume, with volume tanks
2	Air filter systems, high pressure microparticle, and spares
1	Oxygen analyzer, Teledyne
1	Helium mixed gas control system, multiple-diver, with interconnects
2	Helium communication unscramblers with headset
2	Radios, air communication with headset
3	Diving hoses, 600', with strength member, communication line, and pneumofathometer hose
2	Emergency ascent bottles with regulators
1	Deck-connect ladder
1	Equipment box containing standard Oceaneering diving gear
1	Set Oceaneering standard advanced decompression tables
1	Set full service technical manuals
1	OSHA first aid kit

Total day rate for above.................. $1,475.00

Total weight.......................... 30,000 pounds

DIVING EQUIPMENT RENTAL SCHEDULE

Diving Equipment:

	Day Rate
Air filter system, high pressure microparticle and spares	$ 25.00
Air manifold control system with interconnects	35.00
Air volume tank	20.00
Bell, Class II open bottom with emergency cylinders and handling system with winch	300.00
Bottles, emergency ascent with regulator	10.00
Bottle racks, 12-24 cylinder capacity	10.00
Compressors, deep water and shallow water, diesel driven, with volume tanks, mounted on protective skids:	
120 cfm	120.00
90 cfm	110.00
50 cfm	90.00
25 cfm or less	50.00
Control room	110.00
Decompression chamber, double-lock with breathing apparatus and communications	150.00
Flags and first aid kits (OSHA requirement)	No Charge
Hose, 300', diving, with strength member, communication line and pneumofathometer hose	30.00
Hose, 600', diving, with strength member, communication line and pneumofathometer hose	50.00
Hot water system, diver, shallow water	200.00
Hot water system, diver, deep water	300.00
Ladder, deck-connect	No Charge
Light, underwater, surface powered with cable	55.00
Hand-held	20.00
Mixed gas control system including mixed gas manifold, high pressure inter-connecting hose, oxygen analyzer and mixed gas regulators	300.00
Pneumofathometer, high accuracy	30.00
Public address system with bull horns, speakers and wire	20.00
Pump, gas booster/high pressure	30.00
Radio, air communication with headset	20.00
Radio, helium communication unscrambler complete with headset	50.00
Stage, divers' with emergency bottles	35.00
Tape recorder	25.00

EQUIPMENT RENTAL SCHEDULE (Continued)

Hydraulic:

	Day Rate
Power supply, diesel driven on protective skid	$165.00
300' hose	75.00
600' hose	150.00
Grinder	70.00
Grinding disc, each	Cost plus 15%
Impact wrench, 1" drive with sockets	85.00
1½" drive with sockets	105.00
C-clamp, specialized	125.00
Chain saw	100.00
Jackhammer with cutting blade	85.00
Specialized or replacement blades	Cost plus 15%
Pipe cutter	Price on Request
Blades	Cost plus 15%
Torque wrench	Cost plus 15%

Jetting:

3" X 2½" pump with suction hose and foot valve	90.00
6" X 4" pump with suction hose and foot valve	120.00
6" X 6" pump with suction hose and foot valve	Price on Request
Hose, per 50' length	25.00
Jet nozzle	10.00

Pneumatic:

Chipping hammer	35.00
Chisels and needles	Cost plus 15%
Gouger	60.00
Grinder	50.00
Impact wrench, 1" with sockets	70.00
1½" with sockets	85.00
Hose, per 50' length	12.00

Waterblaster:

Waterblaster, high pressure, diesel driven with supply pump and gun	255.00
Hose, per 50' length	45.00
Nozzle, high pressure	Cost plus 15%

EQUIPMENT RENTAL SCHEDULE (Continued)

Welding/Cutting:

	Day Rate
Burning gear, topside, oxygen-acetylene	$ 50.00
Burning gear, underwater with 300' burning lead, ground lead, torch head and knife switch, oxygen regulator, oxygen hose and burning gear box	115.00
Burning gear, underwater with 600' burning lead, ground lead, torch head and knife switch, oxygen regulator, oxygen hose and burning gear box	175.00
Burning rods, underwater	Cost plus 15%
Welding gear, topside	40.00
Welding gear, underwater with 300' welding lead, ground lead, electrode holder, knife switch and welding gear box	100.00
Welding gear, underwater with 600' welding lead, ground lead, electrode holder, knife switch and welding gear box	160.00
Welding machine, diesel driven	
400 A	80.00
600 A	120.00
Welding rods, underwater	Cost plus 15%
Topside grinder	20.00

Miscellaneous:

Air lifts, up to 8" (only charged on days used)	55.00
Air tugger	
1000#, without cable	30.00
2000#, without cable	75.00
4000#, without cable	85.00
Cable for tuggers	Cost plus 15%
Banding tools	20.00
Bands and clamps	Cost plus 15%
Cable cutter, 1"	65.00
Flange spreader set	10.00
Hoses, standard for all pneumatic tools, per 50' length	12.00
Magnetic particle inspection device	150.00
Potentiometer	60.00

EQUIPMENT RENTAL SCHEDULE (Continued)

Miscellaneous

	Day Rate
Probes, high pressure air and water	$ 10.00
Ultrasonic thickness device, underwater or remote readout capability	125.00
Photographic:	
35 mm still underwater system, including strobe and close-up attachment	90.00
35 mm still underwater system with strobe, 300' maximum depth rated	150.00
35 mm still surface camera	20.00
Film, processing and printing	Cost plus 15%
T. V. systems with video and audio	275.00
Video tape editing	Price on Request
Video tape	Cost plus 15%
Tool boxes:	
Inspection - dividers, gauges, tape measures, contour gauges, squares and levels	30.00
Offshore - pipe wrenches, hammers, hand saw, spud wrenches, miscellaneous hand tools	30.00
Rigging - up to 4, 2-wire and 2 chain come-alongs, 12 shackles, 3 snatch blocks and 4, 10' lengths of chain	80.00

Transportation:

	Rate per Mile
Automobile	$ .70
Carry-all/Van	.90
¾-ton pick-up	.80
1-ton flatbed truck	1.20
1-ton truck with mini-float	1.90
2½-ton truck with 20' bed	2.25

Driver:

	Rate per Hour
First 8 hours	$ 15.00
Overtime hour after 8 hours	22.50

OFFSHORE WORK BOAT

M/V Mr. Cliff, with 4 man crew .... Prices on Request

Particulars:	Length 120' Beam 30' Depth 13' A.B.S. Load Line, U.S.C.G. Certified Official #571431 Gross Tons: 98.6 Net Tons: 65 Fuel Capacity: 36,000 gallons Water Capacity: 60,000 gallons Twin Screw HP 1600 Clear Deck Aft: (with winch) 57' X 30' (without winch) 70' X 30'
Machinery:	Engines: two V-12 149 GMC Generators: two 60 KW
Communication:	S.S.B. Radio SBA Model SBA-356 VHF - Radio Hy-Seas 55
Navigational:	Radar: Decca RM 914A - Scanner Class X Type: 65147 Depth Recorder: Fathometer type H E 103C Loran: Morrow Loran "A" Model L D 4
Quarters:	4 Man crew and 12 others Full galley Showers Sanitation system

INVOICING GUIDELINES

Labor:

1. A diving day is from midnight to midnight.
2. Twelve hours is the minimum charge for an offshore workday. Eight hours is the minimum charge for an inshore workday. Hours worked in excess of the minimum will be at overtime rates. Any part of an hour worked will be billed as one full hour.
3. If the designated hour of embarkation is between the hours of 0001 and 1800, a minimum charge of 12 hours will be levied; if the designated hour of embarkation is between the hours of 1801 and 2400, a minimum charge of 8 hours will be levied. However, if a dive is made in this time period, a minimum charge of 12 hours will be applicable.
4. If the hour of debarkation is between the hours of 0001 and 0600, a minimum charge of 8 hours will be levied. However, if a dive has been made within that time period, a minimum charge of 12 hours will be applicable. If the hour of debarkation is between the hours of 0601 to 2400, a minimum charge of 12 hours will be levied.
5. If the point of embarkation is in excess of 150 miles from the personnel base, personnel rates will commence upon reaching that 150 mile limit in lieu of the designated point of embarkation.
6. On location, time starts on the hour called to work and ends when the diving station is secured. When a diver is called to duty less than 6 hours after he has secured his station, his time will not be broken.
7. Personnel on standby offshore will be charged as hours worked.
8. A depth premium will be charged for the deepest dive made by each diver in each day. There will be only one depth premium charge per day per diver, regardless of the number of dives each diver makes.
9. If a job is cancelled after the crew departs for the point of embarkation, an 8-hour day will be charged. There will be no charge other than mobilization if the job is cancelled before the diver departs.

INVOICING GUIDELINES (Continued)

Equipment:

Equipment (Operating and Stand-by)

1. Operating Time - Vessels

   Operating time from Oceaneering's base at Morgan City, Louisiana to and from a client's location, or from a client's location to a client's location, will be charged in full to the client.

   Stand-by Time - Vessels

   The full daily or hourly rental rate will be charged when the equipment is stand-by due to bad weather or other causes beyond Oceaneering's control. The decision to stand-by due to bad weather or other causes beyond Oceaneering's control will be at the sole discretion of Oceaneering.

2. Maintenance Time - Vessels

   Client shall allow Oceaneering up to eight hours of paid time during any breakdown for the repair or maintenance of the lay barges, jet barges, work barges and derrick barges in each of the above cases. Client shall allow pay for lost time up to 24 hours during any breakdown of any self-propelled boat. All other charges for personnel and equipment shall continue.

3. Client will be billed at replacement cost plus 15% for all equipment, tools, anchors, cables and supplies lost or damaged, when not due to the sole negligence of Oceaneering International.

4. Jobs requiring special tools and equipment not normally available at Oceaneering's shop will be billed at cost plus 15%.

5. Other

   In connection with the operation of any Oceaneering supplied vessel, whether owned or chartered, Client assumes all responsibility for locating, identifying and marking with buoys or other appropriate markers, all pipelines, platforms, wellheads, telephone cables, power cables, sunken ships and other obstacles near or in the vicinity of the work to be performed by Oceaneering which may be damaged by anchoring or otherwise affect anchoring operations. Client shall direct the placement and recovery of all anchors to prevent damage to pipelines or other obstructions in the area. Client shall indemnify Oceaneering International against and hold it harmless from all direct and consequential losses, damages, liabilities, costs and expenses, including reasonable attorney fees, arising from or in any way connected with the existence or location of such obstacles and any pollution, contamination, and damage to personnel or property and equipment whether owned by Oceaneering, Client, or others resulting therefrom or connected therewith.

INVOICING GUIDELINES (Continued)

Materials and Outside Services:

1. Insurance required in excess of those stipulated herein, such as surety performance bonds, will be billed at cost plus 15%.

2. Jobs requiring special tools and equipment not normally available at Oceaneering International, Inc.'s shop will be billed at cost plus 15%.

3. Food and lodging provided both onshore and offshore by Oceaneering will be billed at cost plus 15%.

4. All materials and consumables, including, but not limited to, fuel, supplies and services will be charged at cost plus 15%.

5. All third party services contracted by Oceaneering as a convenience to the customer will be charged at cost plus 15%. Under no circumstances does Oceaneering assume responsibility for the adequacy of third party services and in particular the performance of their personnel and equipment.

6. Vessels chartered on behalf of client will require Charterer's Legal Liability Insurance which will be billed at cost plus 15%.

INVOICING GUIDELINES (Continued)

Mobilization, Installation and Demobilization:

1. Yard labor for load-out and load-in of equipment will be charged at $12.00 per hour per person during normal working hours and $18.00 per hour per person outside normal working hours. Oceaneering yard cherry picker will be charged at $50.00 per hour. Oceaneering yard 100-ton crane with two riggers will be charged at $150.00 per hour. There will be a 2-hour minimum for the cherry picker and 100-ton crane.

2. The client will provide means for lifting the diving equipment offshore and at the dockside.

3. Mileage is charged from and to personnel base. Third party transportation equipment handling will be charged at cost plus 15%.

4. Mobilization and demobilization will be quoted separately in the event a particular job requires specialized equipment and/or specialized fabrication.

APPENDIX E

DIVING CONTRACTOR GENERAL PROVISIONS

COURTESY OF OCEANEERING INTERNATIONAL, INC.

MORGAN CITY, LA

GENERAL PROVISIONS

Unless expressly stated otherwise, all diving and related services rendered will be in accordance with the terms and conditions of the **General Provisions, Invoicing Guidelines, Insurance,** and **Rental Rates** set forth herein.

Performance of Work

Contractor shall carry out its operations hereunder and under any Contract Service Order with due diligence and in a safe, workmanlike manner, and according to good industry practices in the area of operations.

Invoicing and Payment

The Contractor will submit monthly invoices in accordance with the Company's instructions. Terms of payment are 30 days, net. Invoices not paid by the Company within 30 days of the date of the invoice shall be subject, at Oceaneering International's option, to a late charge of 1½% per month of the amount due and owing Contractor plus 25% attorney's fees due on principal and interest if placed in the hands of an attorney for collection. Failure to pay any invoice when due may result, at the option of the Contractor, in suspension of the performance of the work contemplated therein by the Contractor. Payment of invoices shall be made in net amounts in the United States of America dollars in the United States in accordance with the Contractor's instructions.

Indemnification

Contractor will bear all cost of damage caused to or the loss of its own equipment used in the execution of the Contract when operated by its own personnel. Consequently, Contractor waives all right of claim against Company in this respect and undertakes to arrange for the same waiver of claims against Company to be endorsed on all Contractor's insurance policies.

Likewise, Company will bear all cost of damage caused to or the loss of Company's property, the property of third parties under lease, charter or bailment to Company (including the drilling vessel), and Contractor's equipment and property when not being operated by Contractor during the term of this contract. Consequently, Company waives all right of claim against Contractor in this respect and undertakes to arrange for the same waiver of claims against Contractor to be endorsed on all of Company's insurance policies.

Each party will bear all cost of injury or death to its own personnel as well as personnel under contract to it which may arise during the execution of this contract, except in the case of negligence or willful misconduct by the other party, in which case the wrongful party shall be liable, and each party agrees to indemnify and hold the other party harmless for such liability. Consequently, except as provided above in this clause, each party waives all right of claim against the other party for all injuries or death to such personnel without prejudice to the rights of the injured party or his beneficiaries.

GENERAL PROVISIONS (Continued)

Limitations

Notwithstanding any other provisions hereof, Contractor assumes no obligations to Company with respect to any damage or loss to property which may be excluded under the insurance provided pursuant to the Insurance Section of this Rental Rate Schedule.

Contractor's liability for claims under the foregoing paragraphs hereof shall not exceed the scope and limits of the insurance coverage provided pursuant to the Insurance Section, and Company shall reimburse Contractor for any costs incurred in connection with said indemnities as to which Contractor is not otherwise compensated by insurance required under the Insurance Section hereof. Contractor shall in no event be responsible or held liable for consequential damages including, without limitation, liability for loss of use of the Work or Company's existing property, loss of products or profits, or business interruption however the same may be caused.

Contractor shall have no obligation, by way of indemnity or otherwise, regardless of Contractors negligence or that of its employees, agents or subcontractors, and regardless of any deficiency in or unseaworthiness of any such equipment, for personal injury or death or property damage or destruction arising out of or in any way related to the use of Contractor's equipment or any equipment of Contractor's subcontractors by any third parties (including other contractors of Company rendering services to Company or subcontractors of said other contractors) or employees of said third parties, or the presence of any such third parties or any of their employees on or aboard any such equipment of Contractor or its subcontractors, regardless of whether the services being rendered by said third parties or their employees are related to the Work being performed by Contractor, all such responsibility being borne exclusively by Company or other party making such use of said equipment or being on or aboard said equipment.

Without limiting the generality of the foregoing, in the event that any damage to or destruction of any property, whether the Work in progress or any existing facility, is not caused by Contractor's negligence or that of Contractor's employees, agents, or subcontractors, Company shall pay Contractor for repairs or replacements at the rate set forth herein; similarly, if and to the extent that any such damage or destruction, even though caused by such negligence, is not within or exceeds such insurance coverage as may be provided by Contractor under the Insurance Section hereof, then Company shall pay Contractor for such repair or replacement at said rates.

Releases from liability and limitations on liability expressed in the Agreement shall apply even in the event of the fault or neglect of the party released or whose liability is limited and shall extend to the directors, officers and employees, and related entities of such party.

Claims and Liens

Contractor agrees to pay all claims for equipment, labor, materials, services and supplies to be furnished by it hereunder and agrees to allow no liens or charges resulting from such claims to be fixed upon any property of Company and any and all co-lessees of Company wholly or partially bearing the cost of operations hereunder. Company may, at its option, pay or discharge any lien or over-due charges for Contractor's equipment, labor, materials, services and supplies under this Contract and may deduct such payments from any sum due, or which thereafter become due, to Contractor hereunder.

Contractor agrees to hold Company harmless of and from any and all claims for taxes or other charges which may be lawfully levied on the wages and salaries of its agents, servants or employees. Contractor also agrees to pay promptly when due any lawful income tax or other similar charge levied on it or its employees by any government agency having jurisdiction over the areas of operation hereunder and to save Company harmless by reason of its failure to do so in any case.

Contractor shall promptly give Company notice in writing of any claim made or proceeding commenced against Contractor for which Contractor claims to be entitled to indemnification under this contract.

GENERAL PROVISIONS (Continued)

Independent Contractor

In the performance of the Work contemplated by this Contract and under any Contract Service Order, Contractor is an independent Contractor with the authority to control and direct the performance of the details of the Work; provided that Contractor shall perform the Work pursuant to Company's instructions and supervision. However, the Work contemplated herein shall meet the approval of Company and be subject to the general rights of inspection and supervision by Company to secure the satisfactory completion thereof.

Force Majeure

Neither party hereto shall be liable for failure to perform, other than to make payments as specified herein or agreed to, when performance is hindered or prevented by fire, blow-out, labor disturbance, the elements, act of God, war, insurrection, revocation, or denial of import or export authorization or any other action of duly constituted governmental authorization authorities, religious holidays or other causes beyond the control of the parties, whether or not similar to the causes herein specifically enumerated. The party prevented from performing for any such cause shall promptly notify the other in writing and shall do all things reasonably possible to remove such cause and shall resume performance hereunder as soon as such cause is removed.

Assignment of Contract

This contract shall not be assigned, transferred, or subcontracted by Contractor, in whole or in part, without the prior consent of Company, which consent shall not be unreasonably withheld.

Company shall have the right, at any time, to assign all or any part of this Contract to a subsidiary or affiliate corporation or to a co-lessee of Company fully or partially bearing the cost of operations hereunder provided that Company shall remain primarily liable for any and all obligations set forth herein in the event any of such designated assignees fails to fulfill any obligations imposed on Company hereunder.

Notices

All notices pertaining to the Agreement shall be in writing and shall be sufficient if delivered in person to the person appointed by Company or Contractor to receive notices, or if sent by certified or registered mail to said party at the address indicated in the Agreement; or to such other address as either Company or Contractor shall advise the other by like notice.

Applicable Laws

Company and Contractor respectively agree to comply with all laws and rules and regulations (including labor laws), Federal, State and municipal which are now or may become applicable to operations covered by this Contract and any Contract Service Order issued hereunder. Also included without limitation are the provisions of Sections 202 (1) and 202 (7), inclusive, of Executive Order 11246, as amended, which Sections of said Order are made a part hereof as though copied in full herein at this point. Furthermore, in connection with this Contract, Contractor shall make the certifications required by it under such Executive Order.

Thesis
S1552 Saltsman
c.1 Diver operated tools
and applications for
underwater construction.